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*Land Systems*
*Muskegon Operations*

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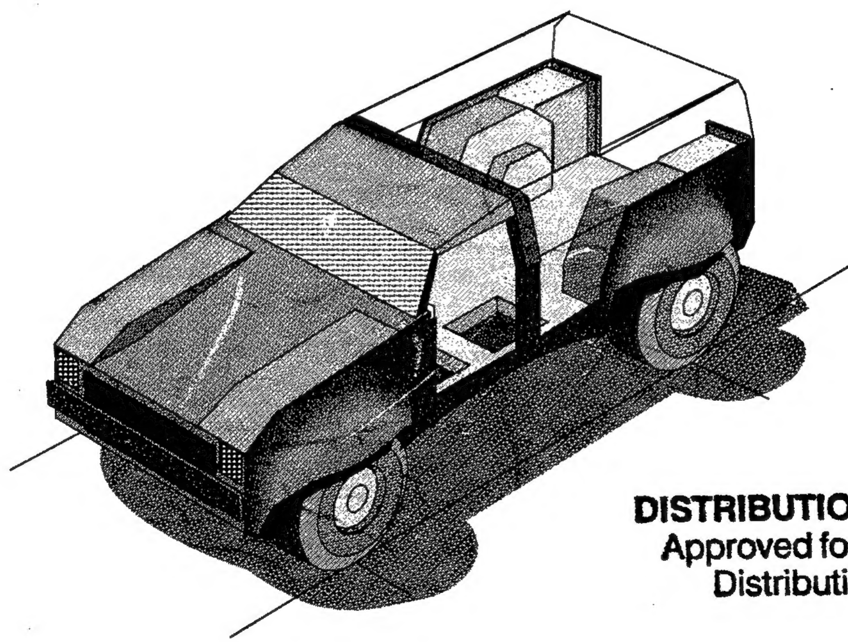
# RSTV CONCEPTS/REQUIREMENTS TECHNICAL REPORT



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**18 DECEMBER, 1996**

**Marine Corps Systems Command**
**Combat Support Logistics Equipment and Training Systems Directorate**
**Quantico, VA 22134-5010**

18 December 1996

# RSTV Concepts/Requirements Technical Report

RSTV Concepts/Requirements Technical Report

Derived from: DoD Directive 5230.24

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. AGENCY USE ONLY** ***(Leave blank)***

**2. REPORT DATE**
18 December 1996

**3. REPORT TYPE AND DATES COVERED**
FINAL

**4. TITLE AND SUBTITLE**
RSTV Concepts/Requirements Technical Report

**5. FUNDING NUMBERS**

**6. AUTHOR(S)**
General Dynamics Land Systems-Muskegon Operations

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Commander, Marine Corps Systems Command
PM, Transportation, Combat Support Logistics Equipment and Training Systems Directorate
2033 Barnett Avenue, Suite 315
Quantico, VA 22134-5010

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Same as block 7 above.

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** ***(Maximum 200 words)***

This report covers the results of the Concepts/Requirements Analyses.

The process used during the concept development and requirements analysis phase of the study consisted of reviewing customer requirements (Draft RSSV System/Segment Specification, LSV Mission Profiles, RSTA/Hunter Mission Statement and various briefing charts), mission analysis, derivation of requirements/capabilities, technology assessments, integration/analyses and finally concept development and trades. Three major iterations were involved in the first phase of this study. Each iteration employed the Pugh design development technique of striving to improve each concept with the best possible combination of features.

**14. SUBJECT TERMS**

| | | |
|---|---|---|
| RSTV | Mission Analysis | System Concept Trades |
| Mobility Analysis | Electrical Subsystems | Mechanical Subsystems |
| Specification Compliance | Concepts/Requirements Analysis | Trade Study |
| Weight Data Sheets | Volume Data Sheets | |

**15. NUMBER OF PAGES**
178

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | SAR |

NSN 7540-01-280-5500

**Standard Form 298 (Rev. 2-89)**
Prescribed by ANSI Std. Z39-18
298-102

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# Introduction

## Introduction

In response to a USMC BAA, GDLS proposed to complete the concept development of a V-22 compatible Recon Scout Vehicle integrating key evolving technologies to provide a high mobility, multi-purpose vehicle fieldable in the post 2000 time frame. A 12 month study effort was proposed wherein the first half concentrated on refining requirements, missions and alternative concepts, while the second half focused on preliminary concept design of the most promising approach.

## Development Process

The process used during the concept development and requirements analysis phase of the study consisted of reviewing customer requirements (Draft RSSV System/Segment Specification, LSV Mission Profiles, RSTA/Hunter Mission Statement and various briefing charts), mission analysis, derivation of requirements/capabilities, technology assessments, integration/analyses and finally concept development and trades. The process proposed for this study is shown in Figure 1. Note that the process involves numerous feedback loops in arriving at the preferred alternative. Three major iterations were involved in the first phase of this study: the original proposal, IPR #1 and IPR #2. Each iteration employed the Pugh design development technique of striving to improve each concept until converging on the concept with the best possible combination of features.

## RST-V Study Schedule

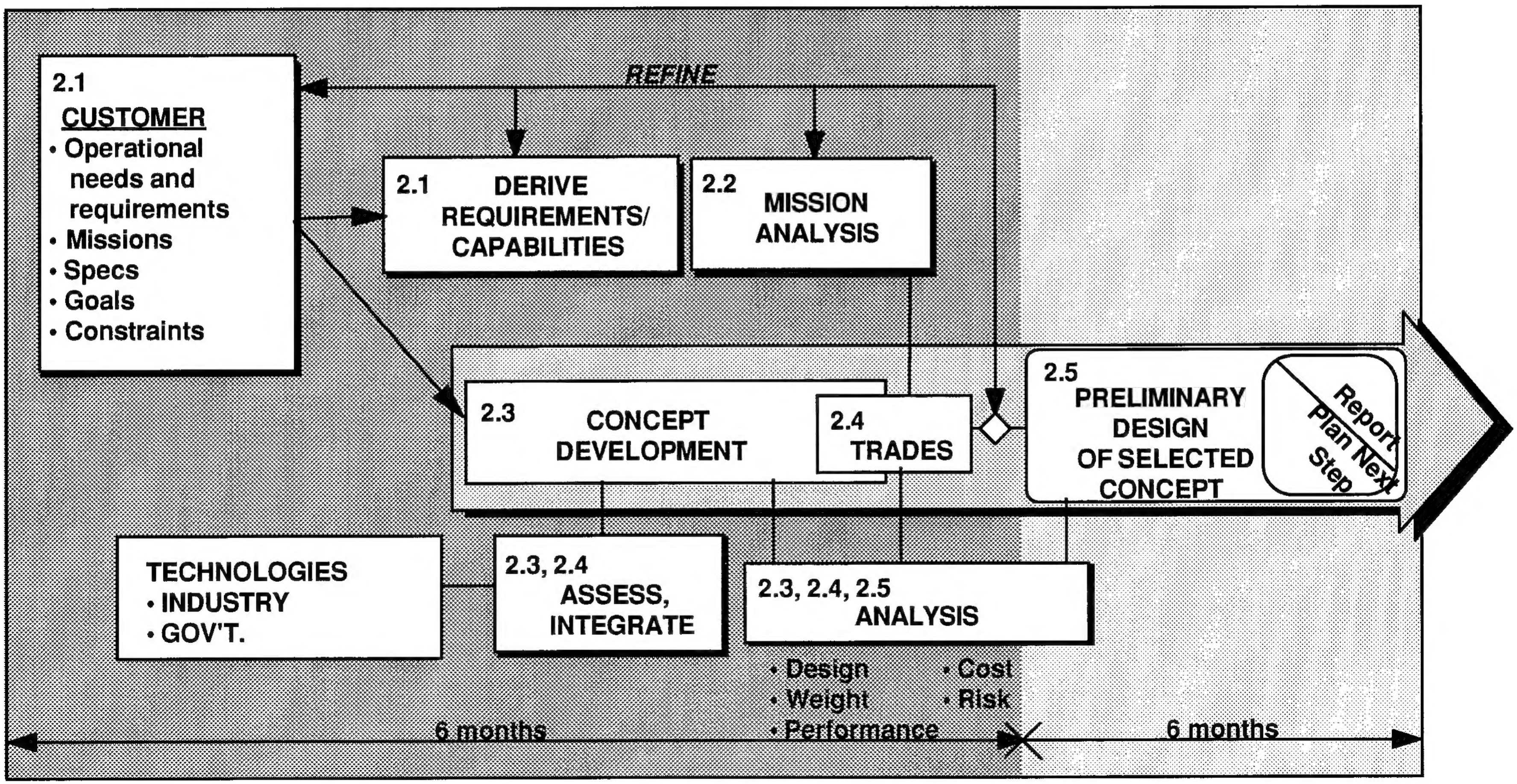
The schedule proposed to develop the RST-V Concept is shown in Figure 2. Four in-process program reviews (IPRs) are planned for the program. The purpose and output of each IPR is as follows:

- IPR #1 (17 Sep 96) Concept analyses status.
- IPR #2 (6 Dec 96) Concepts/Requirements Technical Report and Briefings including vehicle concepts, weight tables, trades, and specification recommendation.
- IPR #3 - (Feb 97) Preliminary design and analyses status.
- IPR #4 - (May 97) Final Technical Report & Briefings including Pro-E CAD model, NRMM data sheets and updated weight tables.

This report covers the results of the Concepts/Requirements Analyses as briefed at IPR #2.

L/

# RSTV Trade Study System Engineering Flow

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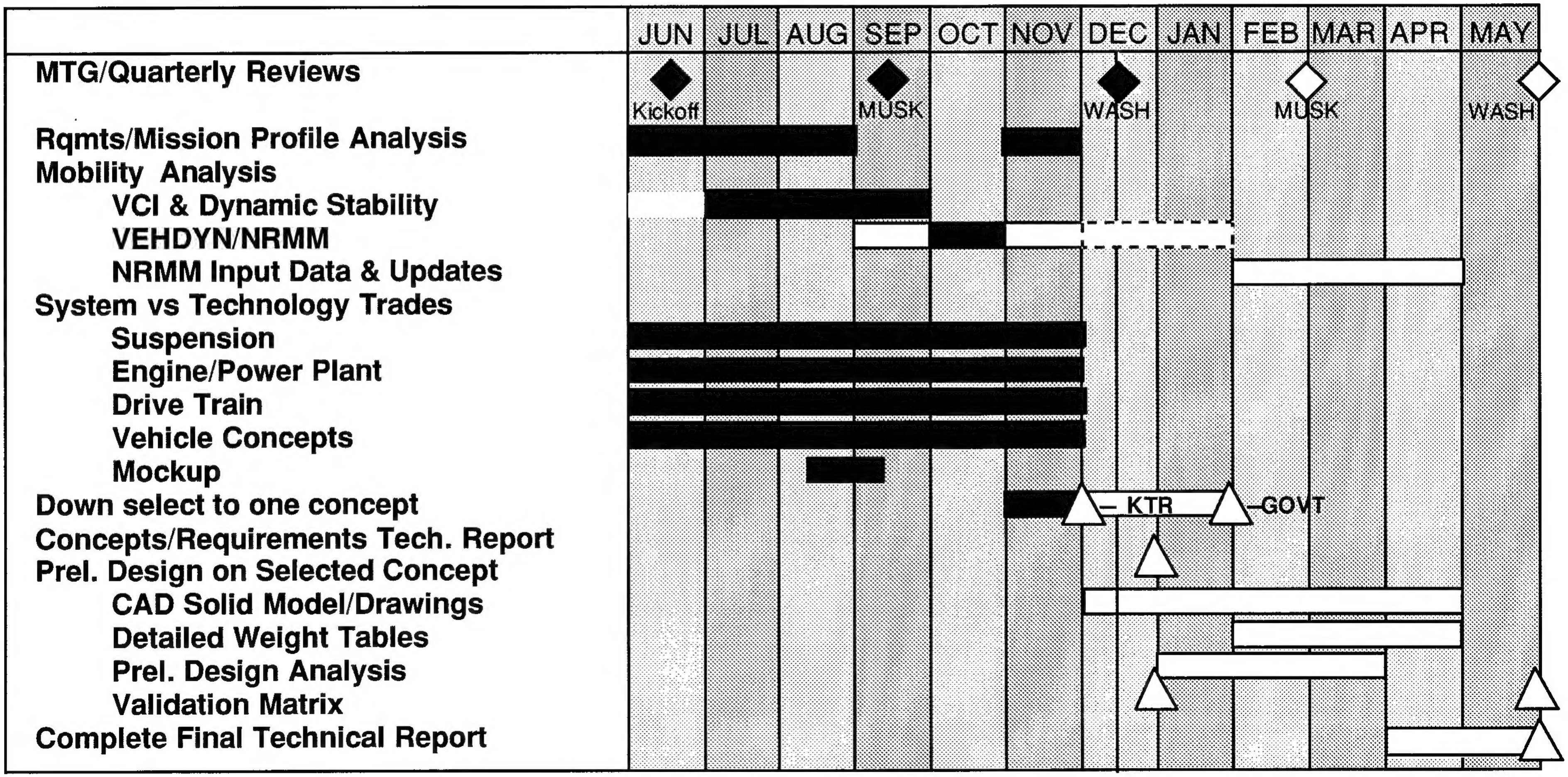
# RSTA-Vehicle Study Schedule
## Status 6 DEC 96



# Mission Analysis

## Reconnaissance, Surveillance, Target Acquisition Mission:

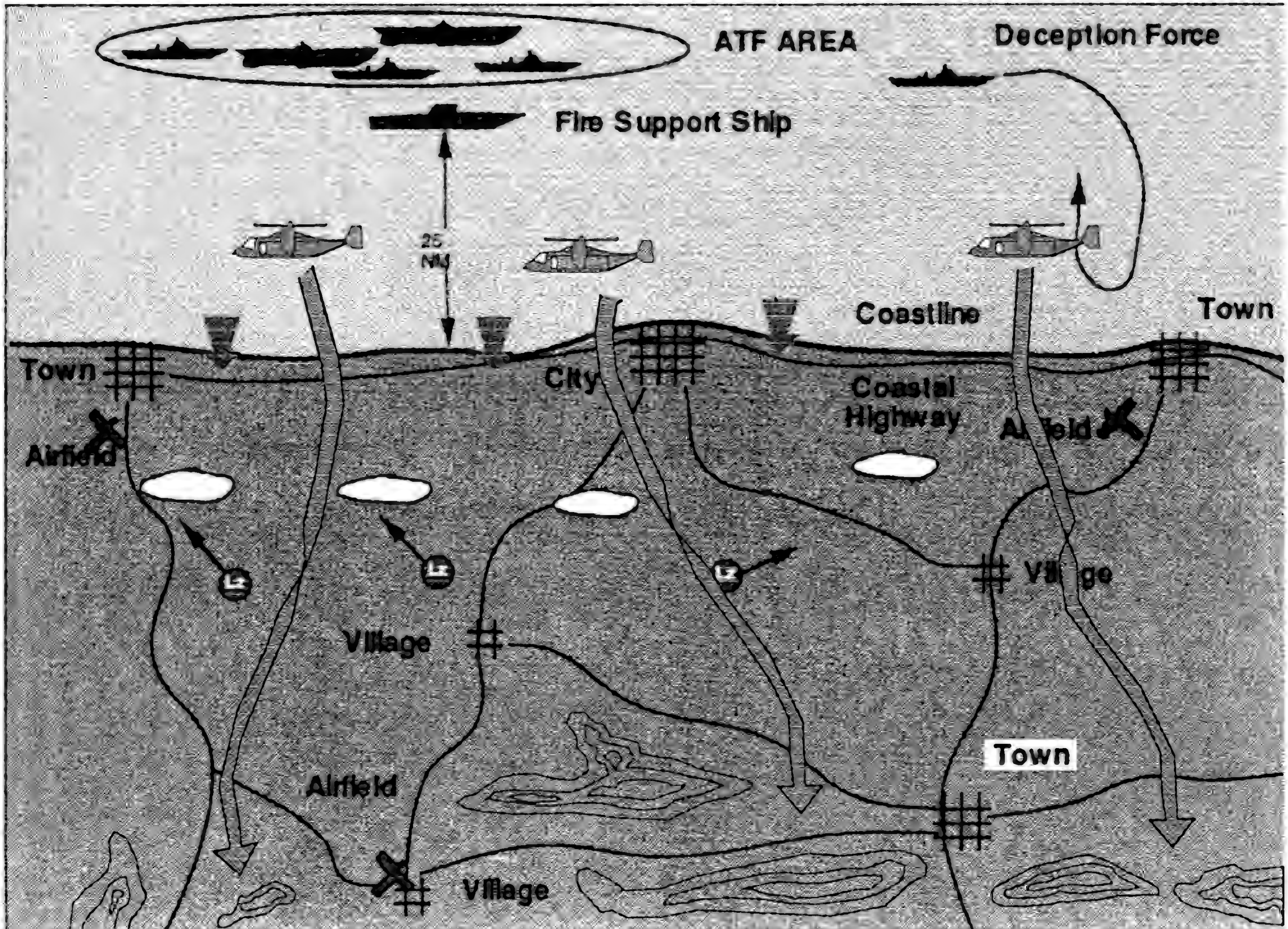
Reconnaissance... A mission undertaken to obtain information by visual observation or other detection methods about the activities and resources of an enemy or potential enemy or about the meterological, hydrographic, or geographic characteristics of a given area.
Surveillance...A systematic observation of airspace or surface areas by visual, aural, electronic, photographic, or other means.
Target Acquisition..The detection, identification, and location of targets in sufficient detail to permit attack by weapons.
Not the Security missions of Screen, Cover, Guard.

To carry out this mission the RSTV will need to carry:

- Land Navigation/Position Location system.
- Communication Equipment cap[able of:
  - Long range
  - Encrypted and burst transmission
  - Digitized data transmission/reception
- RST Suite providing day/night (thermal) capability and targeting as a minimum .
  - growth potential (aural, seismic, sensor fusion, etc...)
- Self defense capability.
  - Sufficient firepower to take out targets of opportunity.
- Weapons and equipment for crew use in independent operations and E&E.
- Rations and water for the duration of the mission (with backup).

The RSTV mission will require:

- Stealthy movement into and out of the hide position.
  - The distance traveled in a stealth mode will depend on METT
  - Distance should be kept as low as possible
    - = Extended travel will mean arrival with drained batteries
    - = The engine will be needed to charge the system and must also be capable of stealthy operation
  - Sudden appearence of hostile forces/ indigenous personnel.
  - Compromise of position.
    - = May require movement over a considerable distance.
    - = May require multiple stealthy periods.
    - = May occur at any time with batteries in low state.
- Stealth means a minimum of noise and heat while stationary and slow deliberate moving, when necessary.
- Speed produces sound , heat and vulnerability to Radar and vision.
  - Sound from tires rolling over branches, leaves, rocks.
  - Sound from the suspension and chassis moving through brush.
  - Heat generated by the wheels/tires and suspension.
  - Rapid movement is picked up by Radar and human eyes.



ATF AREA
Deception Force
Fire Support Ship
25 NM
Coastline
Town
Town
City
Coastal Highway
Airfield
Village
Village
Airfield
Village
Town


9

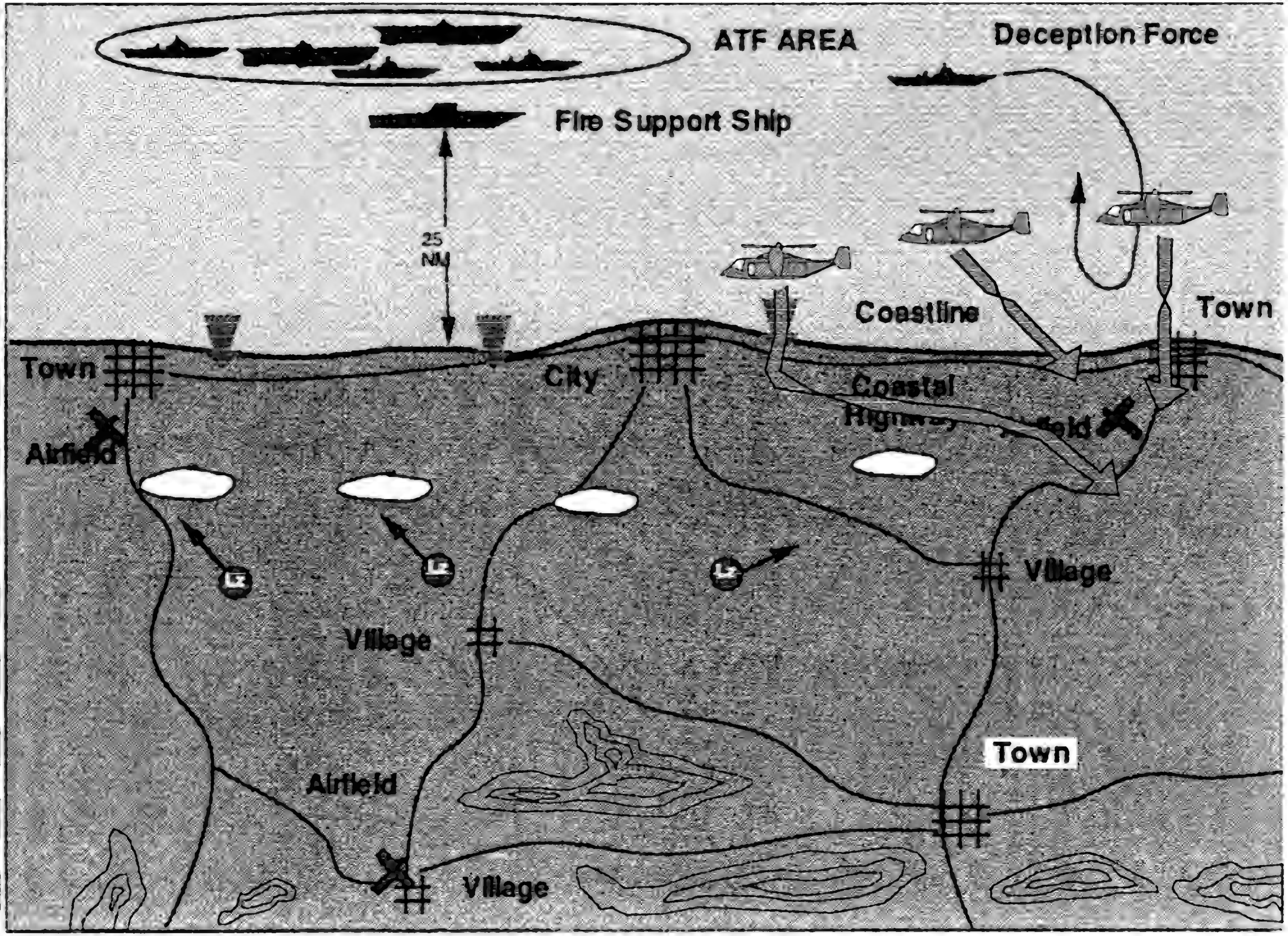
# AMPHIBIOUS RAID MISSION

Amphibious Operation...An attack launched from the sea by naval and landing forces, embarked in ships or craft, involving a landing on a hostile shore.
Raid...An offensive tactical operation, usually of small scale and based on good intelligence, involving swift movement into hostile territory to secure information, confuse the enemy, destroy his installations, or liberate personnel, and ending with a planned withdrawal.

To carry out this mission the unit must:
- Overrun and seize the objective with the maximum surprise, violence and firepower.
- Be prepared to hold the objective and repulse the enemies counterattacks until the mission is completed.
- Be prepared to conduct a fighting withdrawal to the extraction point and to defend that point until extraction is complete.

This mission will require V-22 transportable vehicle(s) that:
- Can carry a modular survival/armor package
- Can approach and withdraw from the objective area with speed.
- Make the final approach under stealthy conditions.
- Can carry an array of firepower packages.
    - Machine guns/grenade launchers
    - Support weapons-mortars, missile launchers, etc...
- Can fill several roles.
    - Weapons carrier
    - C2
    - Personnel carrier
    - Ambulance

Reasons for employment of a number of vehicle variants:
- Command & Control from a V-22 transportable platform allows the raid commander to control the units employed, communicate with higher headquarters, and coordinate supporting arms.
- Direct fire weapons employment from V-22 transportable platforms.
    - Grenade launchers for direct fire area coverage
    - Machine guns for suppression, and support of ground elements
- Heavier support weapons on a V-22 transportable platform.
    - Mortars for heavy fire support and smart anti-armor.
    - Missile launchers (Javelin, TOW) for anti-armor/Bunker busting.
    - Missile launchers (Stinger) for anti-air/helicopter.
- A V-22 transportable personnel carrier for the ground combat teams frees space in the fire support vehicles for increased ammunition stowage and provides space for prisoners or recovered personnel/equipment.
- A V-22 transportable Ambulance will facilitate the recovery and transport of POW personnel that may be in poor physical condition.


ATF AREA
Deception Force
Fire Support Ship
25 NM
Coastline
Town
City
Coastal Highway
Airfield
Village
Town
Airfield
Village
Village
Town

# AIRFIELD SEIZURE MISSION

ASSAULT...A phase of an operation beginning with delivery of the assault force into the objective area and extending through the attack and consolidation of the objectives.
SEIZE...To take possession of.
RETAIN...A mission requiring a unit to specifically prevent the enemy from occupying a position, terrain feature or manmade object.

To carry out this mission the unit must:

- Isolate, overrun and seize the objective with the maximum surprise, violence and firepower.
- Be prepared to hold the objective and repulse the enemies counterattacks.
- Be prepared to conduct this defense until the primary force arrives and the mission is completed.

This mission will require a V-22 transportable vehicle(s) that:

- Can carry a modular survival/armor package
- Can approach and withdraw from the objective area with speed.
- Make the final approach under stealthy conditions.
- Can carry an array of firepower packages.
    - Machine guns/grenade launchers
    - Support weapons-mortars, missile launchers, etc...
- Can fill several roles.
    - Weapons carrier
    - C2
    - Personnel carrier
    - Ambulance

Reasons for employment of a number of vehicle variants:

- Command & Control from a V-22 transportable platform allows the raid commander to control the units employed, communicate with higher headquarters, and coordinate supporting arms.
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    - Mortars for heavy fire support and smart anti-armor.
    - Missile launchers (Javelin, TOW) for anti-armor/Bunker busting.
    - Missile launchers (Stinger) for anti-air/helicopter.
- A V-22 transportable personnel carrier for the ground combat teams frees space in the fire support vehicles for increased ammunition stowage and provides space for prisoners.
- A V-22 transportable Ambulance will facilitate the recovery and transport of wounded personnel to a central collection point.

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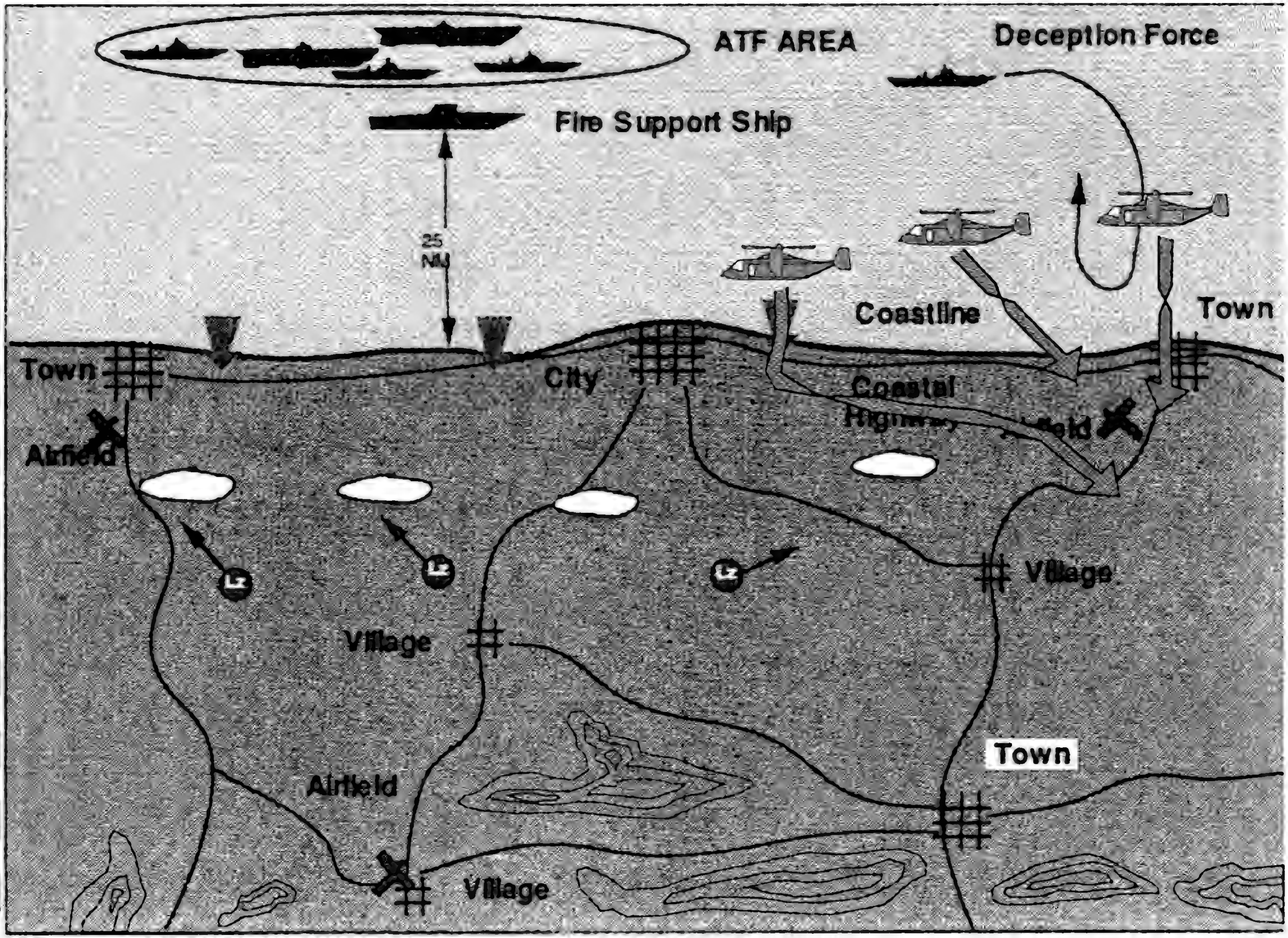
ATF AREA
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Coastal Highway
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Village
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Airfield
Village
Town
Airfield
Village
LZ
LZ
LZ

# RSTV CHASSIS VARIANTS

Mission analysis demonstrates the need for additional variants of the basic RSTV chassis for successful mission accomplishment and maximum use of the V-22 assets. These variants include but are not limited to:

- Personnel carrier for assault/snatch teams and sufficient space for recovered personnel and/or POW's and hostile prisoners. The vehicle will carry a machine gun for protection and to support the mounted team.

- Light Strike Vehicle or Light Fire Support Vehicle armed with machine guns or grenade launchers. Heavy machine guns and grenade launchers will provide materiel damaging and suppressive fires during the course of the mission.

- Heavy Fire Support Vehicle mounting fire-and-forget missiles (Javelin, FOG-M) for anti-armor and bunker busting, and the 120mm mortar for heavy fire support and anti-armor with smart rounds (Strix). The chassis built in pneumatic system will provide power to deploy and recover heavy weapons such as the mortar within a matter of seconds. The illustration shows only one of several methods to deploy the mortar off the back of the chassis and transferring the firing forces to the ground.

- Anti-Helicopter and Anti-Air support can be provided by mounting Stinger missiles on the chassis. The mounting would be a simpler mount than the Avenger turret presently used.

- An ambulance can be configured on this chassis that would be capable of 4 stretchers in an enclosed body and more if an open body were preferred.

- A Command and Control version would feature a radio and display suite sufficient to give the Commander control over his units and supporting arms. A slightly different configuration would produce a Fire Support Coordination Center Vehicle for battalion operations.

- A reduced capability RSTV suite would provide the Forward Air Control parties and Artillery Forward Observers with increased capability and mobility in the air assault that would be available immediately upon touchdown.

Additional mission requirements can be met by this concept and most mission modules used on the HMMWV can be used on this chassis.

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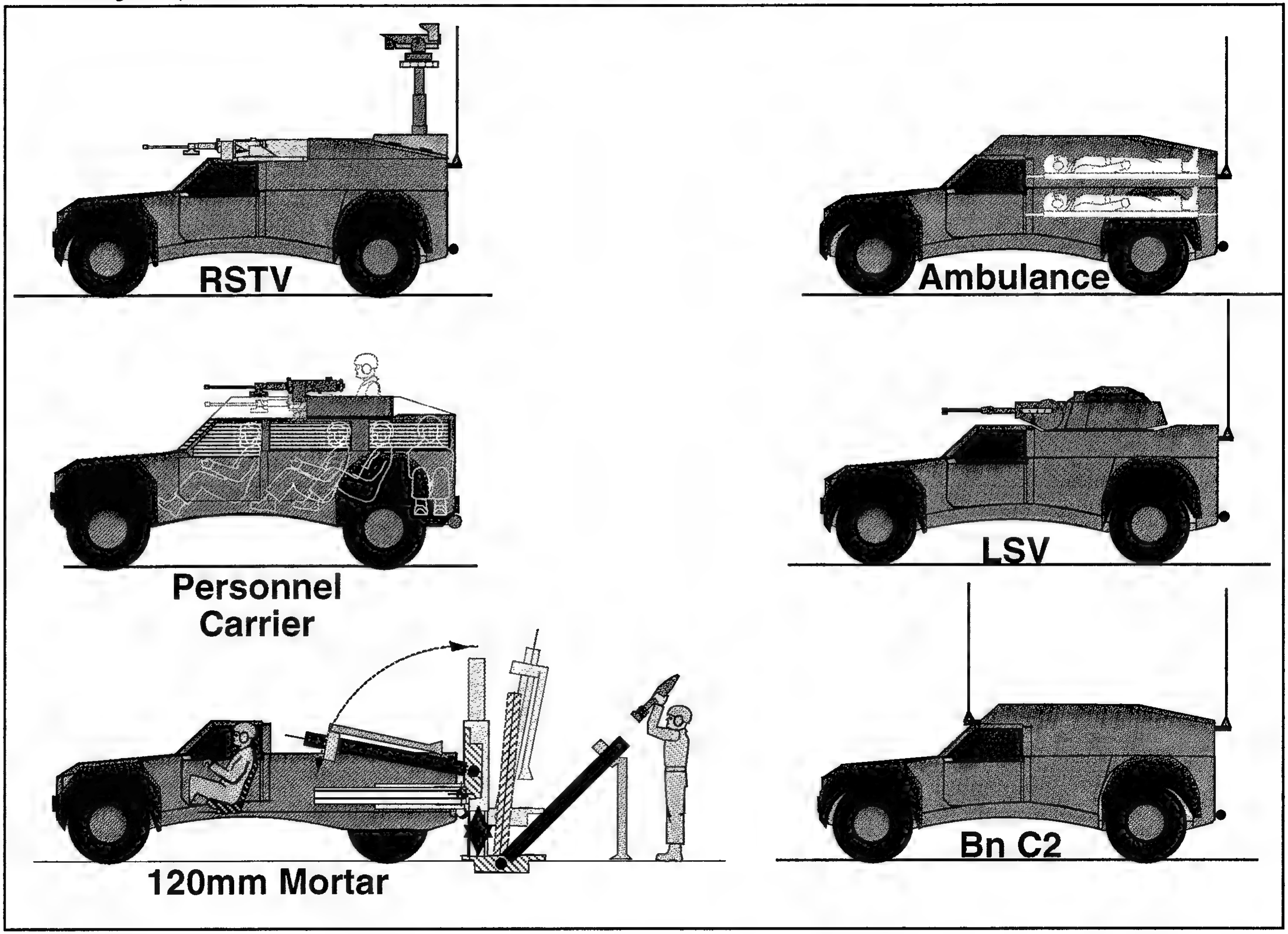
# RSTV AND VARIANTS

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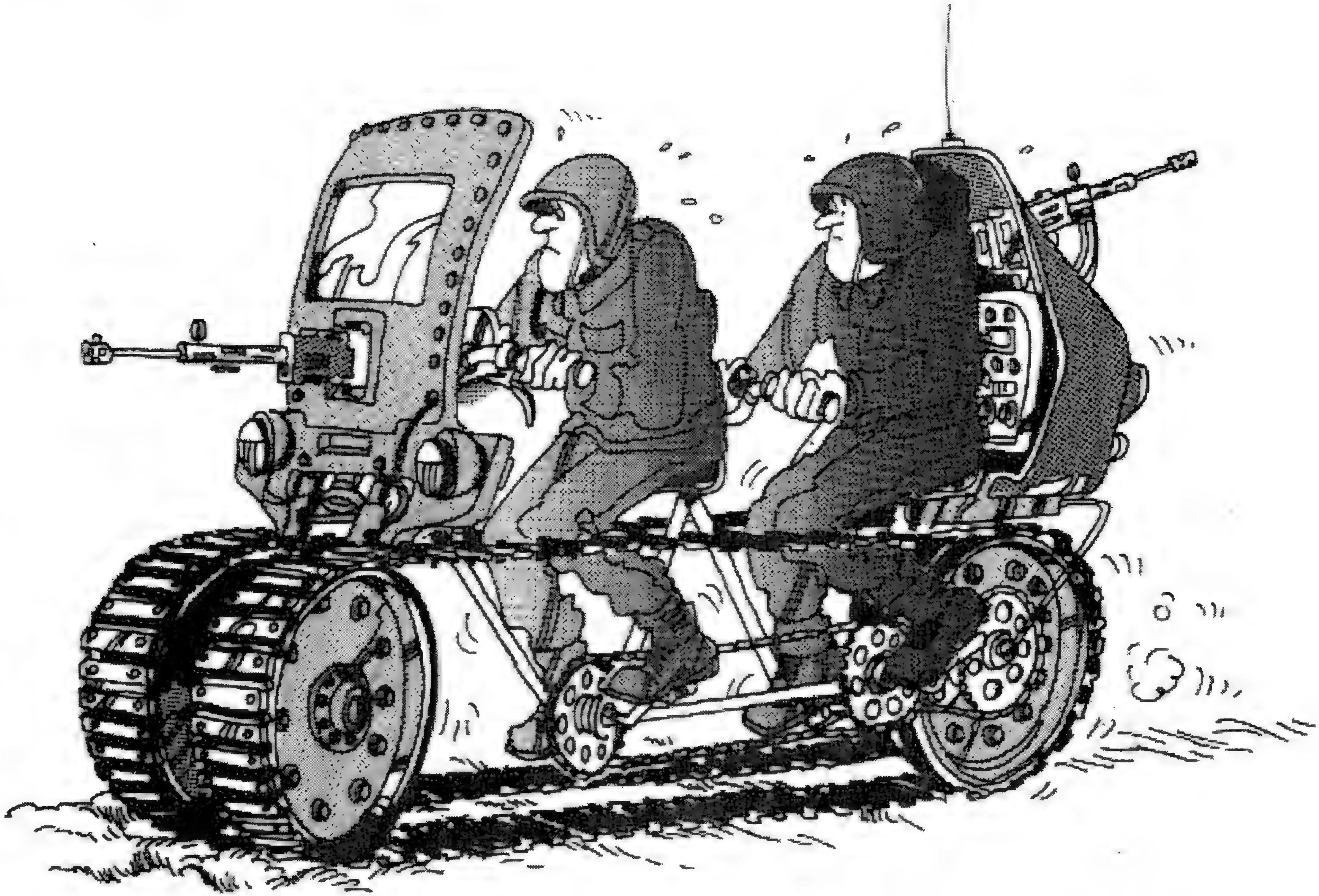
# Concept Assessment Criteria

| | |
|---|---|
| Cost | Demonstration Cost, Development Cost, Production Cost |
| Risk | Demonstration (2000), Production (2004) |
| V-22 Compatibility | Weight, Volume, Ramp Angle |
| Mobility | Road & Cross Country Speed<br>Obstacle Capability |
| Utility/Mission Payload * | Ingress/Egress (side & rear), Useable Volume, Weight Capacity, Mount Provisions |
| Survivability | Stealth, ballistic protection, Agility, Silhoutte |
| Safety | Operator, Maintenance |
| RAM/Logistics | Commonality, Part Count, Repairability, etc. |

* RSTA Sensor Carrier, Personnel Transport, Weapon Carrier, Litter Carrier

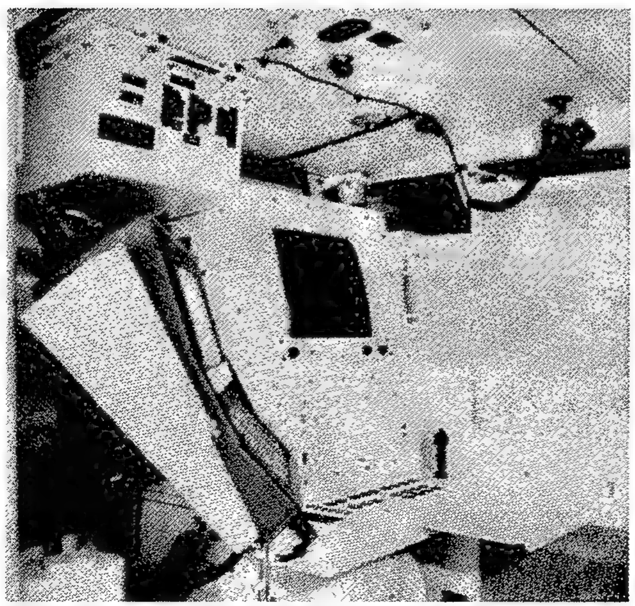


RSTV VERSION PROVIDING 12 INCH CLEARANCE FROM V-22 FUSELAGE

# EXAMPLE RSTA SUITE

CANADIAN LAV RECCE

- EXISTING IN-PRODUCTION UNIT
- ~500-600K COST W/O RADAR
- LEAST RISK FOR NEXT PHASE



# System Concept Trades

## RST-V Concept Tree

Four key configuration issues were considered in the system (top level) trade study. The first configuration issue was the type of traction method to be used for the vehicle, i.e. wheel vs. track vs. a hybrid combination of wheels and tracks. Based on the type of traction the next issue became the number of traction devices which further defined the hull configuration. Once the type of traction was identified including hull configuration, the issue became that of what was the best way to integrate the drive method i.e. location and type of traction motors. The final top level issue hinged on the energy storage method. Each of these mini-trade issues impacted the other such the process required several iterations to arrive at the best definition of each concept.

## RST-V Concept Tree (First Pass)

Each of these concepts utilized the length of the HMMWV as a starting point while maintaining the required maximum reducible height of 55 inches and width of 65 inches (68 inches minus 1.5 inches per side for clearance) for V-22 compatibility. These concepts incorporate the following feature identified in the original proposal:

- Maximize useable volume within V-22 constraints through in-hub drive motors, folding suspension and advanced structure concepts.
- Maximize suspension performance through the use of pneumatics to achieve load management/height control, ride control, roll control.
- Maximize on/off road mobility through the use of multiple wheel drive motors and advance wheel/track combinations.
- Designed-in stealth features for visual, thermal, acoustic etc.

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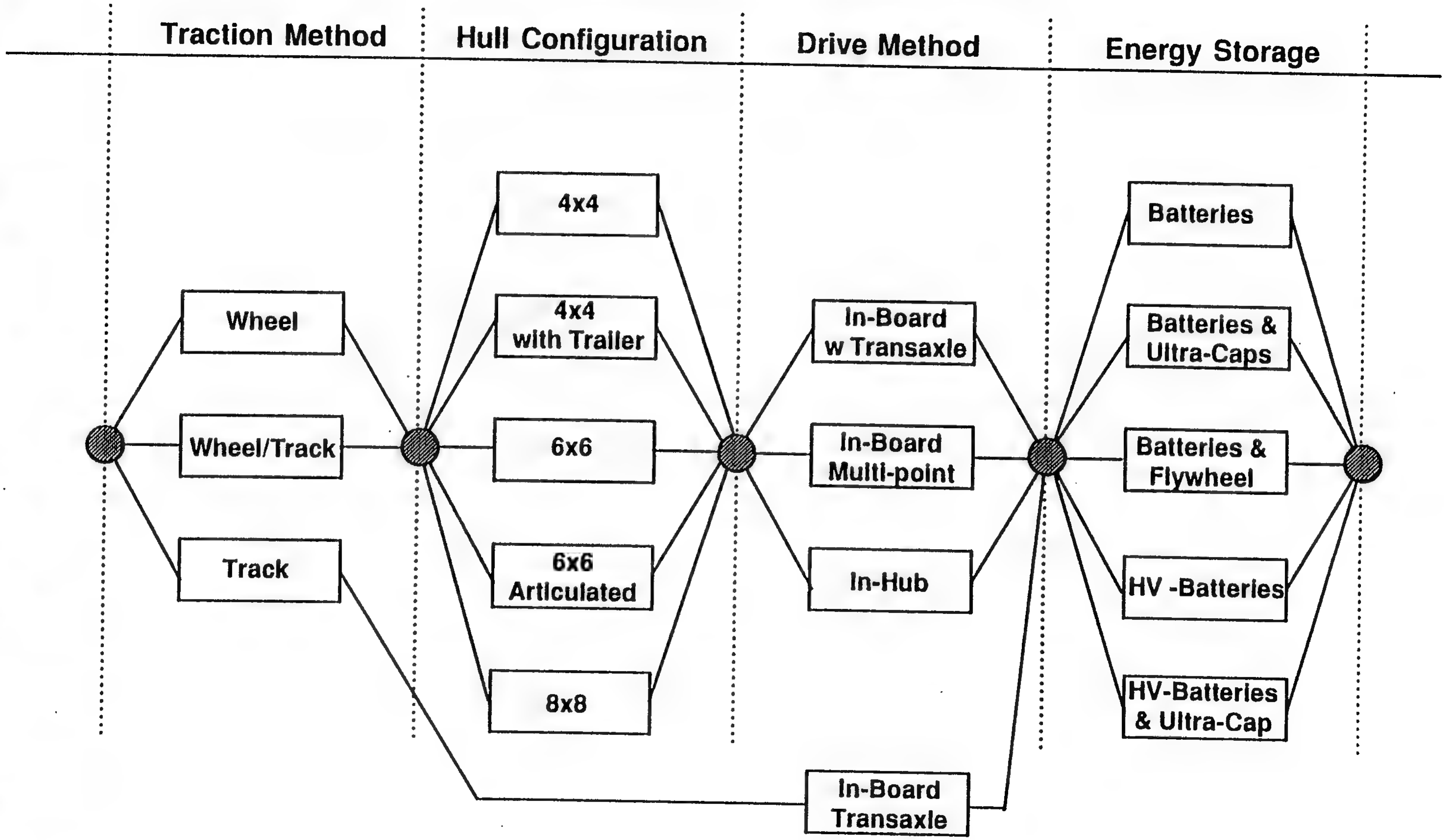
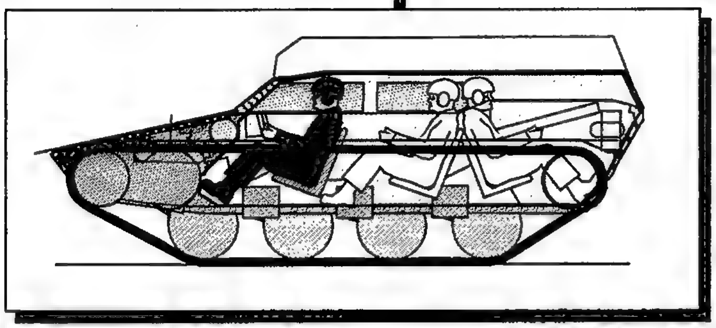
# RSTV Concept Trade Tree

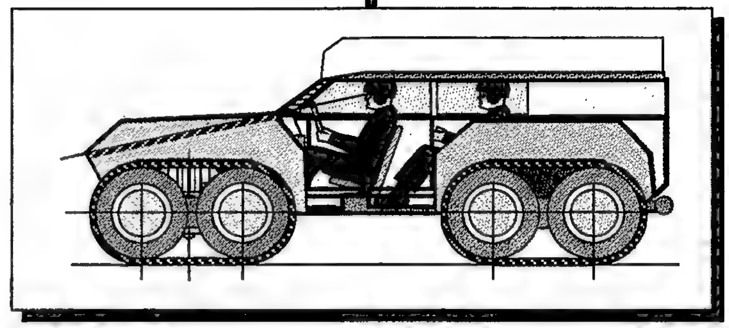


# RST-V CONCEPT TREE (First Pass)

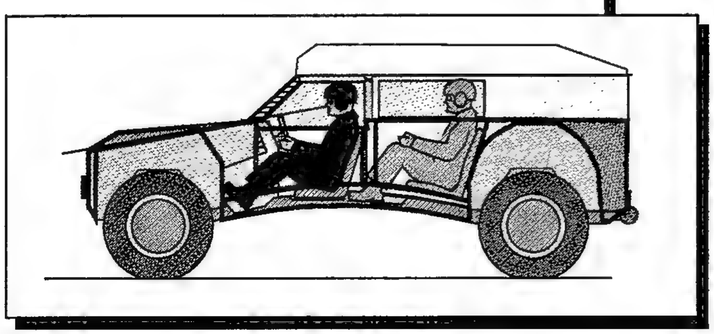
TRACKED



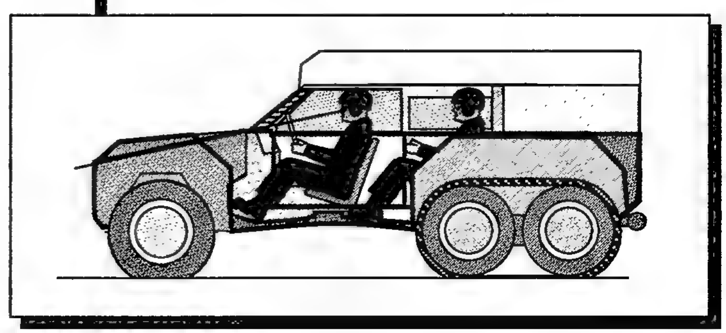
8X8



4X4



6X6



## RST-V Mockup Photographs (4x4, 6x6 and Tracked)

A reconfigurable, full scale, wooden mockup was built prior to IPR #1 to assess stowage and operator implication of each of the principle alternatives. The 4x4 concept demonstrated excellent ingress/egress with four large side doors and rear access derived from the long wheelbase (130 in.) and low flat floor. Note that User (SOCOM) input during IPR #1 was that three abreast was probable not practical for extended periods of time due to the crew's load bearing equipment.

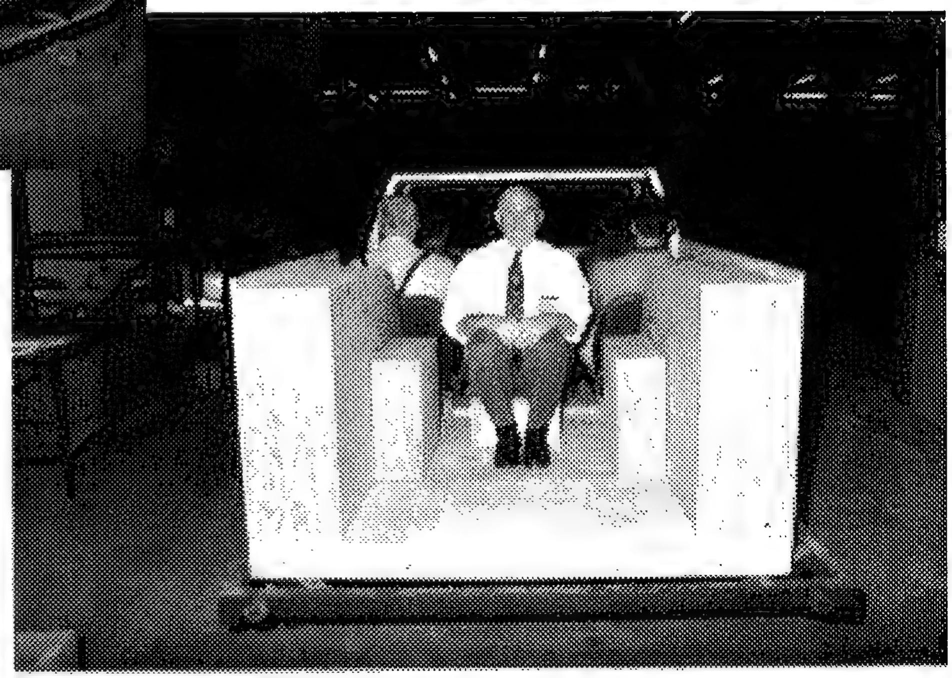
The principle impact from adding a second set of wheels (6x6 concept) to the baseline is the lost of two side doors and the ability to sit three abreast behind the driver. Note the tight fit for the rear passengers and the apparent loss of stowage volume with a crew of six.

The principle impact of adding tracks to the baseline concept is the loss of all side doors and the ability to sit side by side (2 abreast). In order to preserve an aisle way for ingress/egress through the rear it was necessary to sit all the passengers side ways. It was also concluded that there was not enough width to sit a crewman next to the driver.

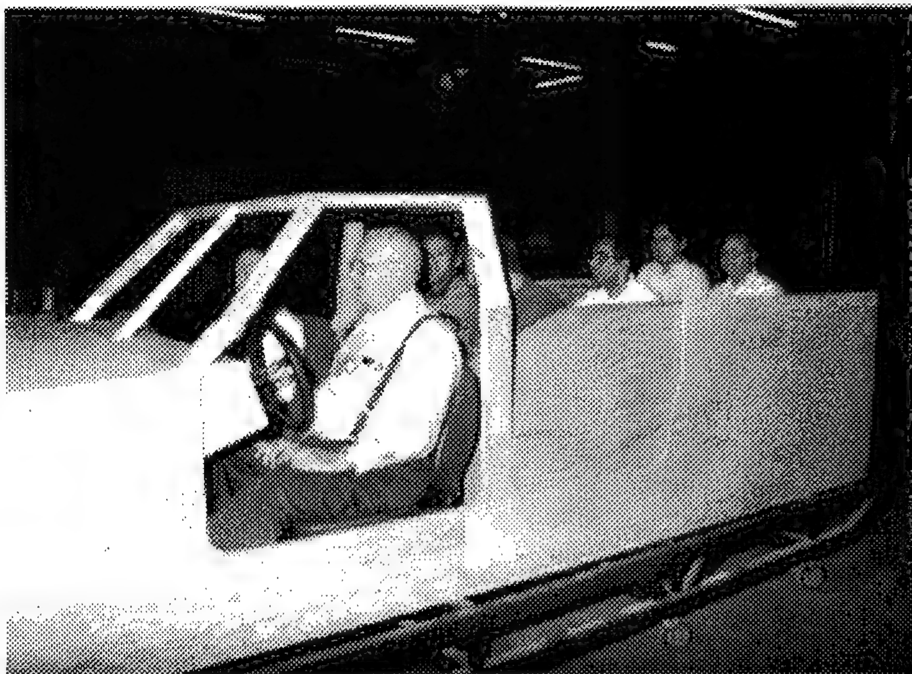
# RST-V Mockup 4x4 Concept

3/4 Side View
- Good side Ingress/egress
- 3 abreast seating - marginal
- Six person seating achieved

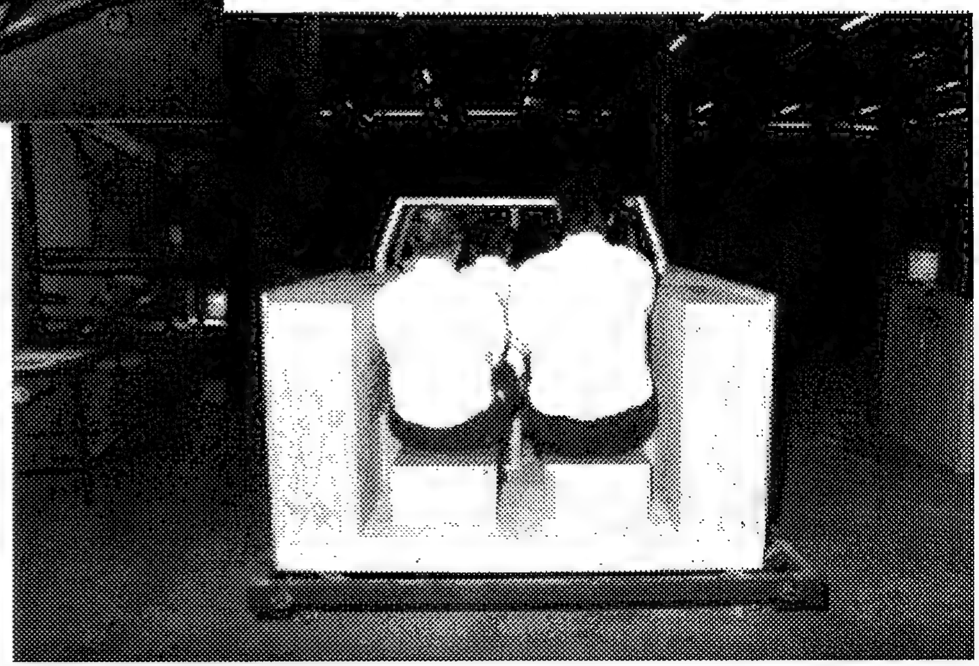
Rear View
- Note low, flat floor
- Good rear ingress/egress
- Space claim for suspension shown



# RST-V Mockup - 6x6 Concept



3/4 Side View
- Limited side Ingress/egress
- 2 abreast seating - marginal
- Six person seating achieved



Rear View
- Good rear ingress/egress
- Useable low/flat floor
- 6x6 space claim limits stowage

# RST-V Mockup Tracked Concept

Rear View
- Good rear ingress/egress
- Side facing seating required for aisle
- Track space claim limits stowage

3/4 Side View
- Poor side Ingress/egress
- 2 abreast seating - marginal
- Six person seating achieved

## RST-V Vehicle Cone Index (VCI)

A key driver of the concept analysis prior to IPR #1 was the initial mobility assessment. The table shown covers the VCI results for the various combinations of tire size, tire deflection, tracks and weight distribution considered. The HMMWV data is also provided for reference. Note that all the combinations achieved the specified VCI values of 15-22 with the exception of the 4x4 with the smaller 7.50R20 tires. The surprisingly good results are attributable to the use of Central Tire Inflation (CTI) systems on the wheeled concepts and low ground pressure on the tracked concepts. Not shown on this chart but of related importance is the RCI values for the terrain's considered. An examination of the soil characteristics evaluated during the "Wheeled versus Tracked Vehicle Study", March 1985, indicated that a vast majority of the soil traversed had RCI much greater than 35 when dry. It was also noted from WES studies, that positive differentials between RCI and VCI of 10 or more produce good mobility. This led to the conclusion that VCI's much less than 22 were of diminishing return. Note that these finding are sensitive to the choice of geographic regions and climates.

## Conclusions IPR #1

A summary of the key findings from the first pass are as follows:

- **VCI** 4x4 and 6x6 meet VCI goal (15-22) using CTI. 8x8 and Track exceed goal. NRMMII shows diminishing gain below VCI's of 25 (RCI typical >35).
- **Weight** 4x4 meets weight goal with low risk. 6x6 meets weight goal with some risk (adv. engine & structure required). 8x8 and tracked concepts presents serious weight challenges.
- **Utility** 4x4 offered superior ingress/egress and most useable volume/utility (based on drawings and mockup assessment). User (SOCOM) expressed desire for more crew and stowage space.
- **Mobility** 8x8 and Track concepts provide superior NOGO capability (observed). Wheeled vehicles meet or exceed tracked vehicles x-country speed.
- **Survivability** Increasing number of driven wheels improves get home capability.

RSTV Vehicle Cone Index (VCI)
Single Pass, Fine Grain (NRMMII, Ver. 2.5.8b method), GVW 8000 lb.

| Vehicle Configuration | Weight Distribution | Deflecton % | 7.50R20 | 9.00R20 | 37x12.5 R16.5 | HMMWV @ 8500lb | HMMWV @ 10,000 lb |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 4x4 | 40-60 | 15 | 29.5 | 23.4 | 20.3 | 20.4 | 22.9 |
| | | 25 | 25.9 | 20.5 | 17.8 | 18.0 | 20.2 |
| | | 35 | 23.7 | 18.9 | 16.4 | 16.5 | 18.6 |
| | | | | | | | |
| 6x6 | 40-30-30 | 15 | 21.7 | 18.0 | | | |
| | | 25 | 19.1 | 15.8 | | | |
| | | 35 | 17.5 | 14.5 | | | |
| | | | | | | | |
| Half Track | 40-60 | 15 | 20.7 | 17.1 | | | |
| | | 25 | 19.0 | 15.9 | | | |
| | | 35 | 18.2 | 15.2 | | | |
| | | | | | | | |
| Quad Track | Uniform | na | 16.0 | | | | |
| 43.5x10 | | | | | | | |
| | | | | | | | |
| Full Track | Uniform | na | 13.7 | | | | |
| 105x10 | | | | | | | |
| | | | | | | | |

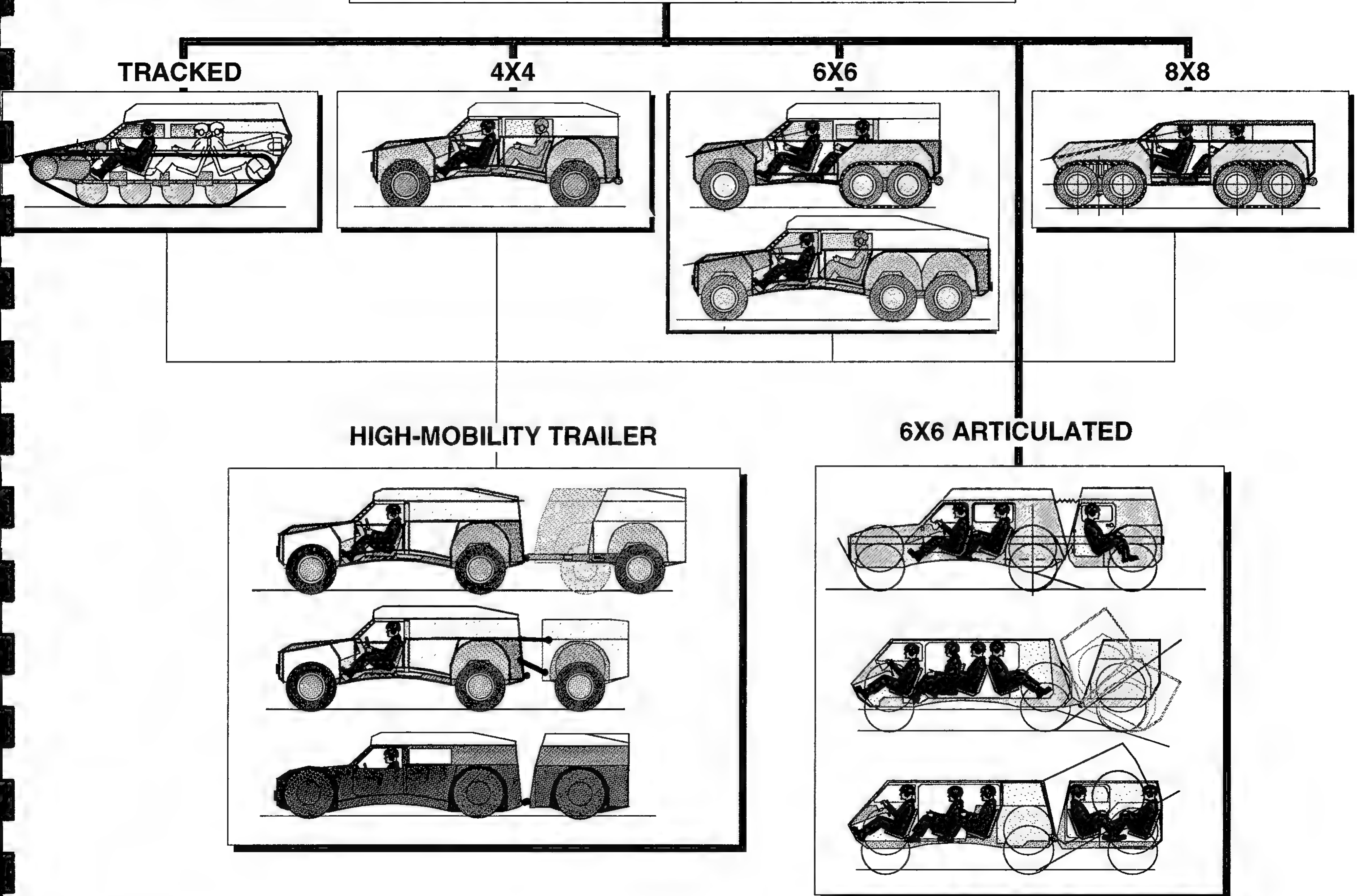
**RSTA-V Concept Tree**

Shown on the next figure are the concepts that were considered for the second pass concept evaluation. Each of the existing concepts were refined where possible to improve in the areas of concern to include: internal volume (SOCOM), obstacle crossing (NOGOs for wheels), hybrid electric capabilities (stealth, fuel economy, and auxiliary power) curb weight, V-22 compatibility (width, height and tie downs) and drive train (in-hub unsprung mass and shock environment).

**RST-V Candidates Under Study**

In additional to refining the initial concepts, it was decided to add an additional variant of the 6x6 including articulation to permit longer length (increased volume) within the V-22. Also, in attempt to increase the volume of the 4X4, a high mobility trailer was added to the study.

# RSTA-V CANDIDATES UNDER STUDY




RSTA-V VIEWS, CANDIDATES

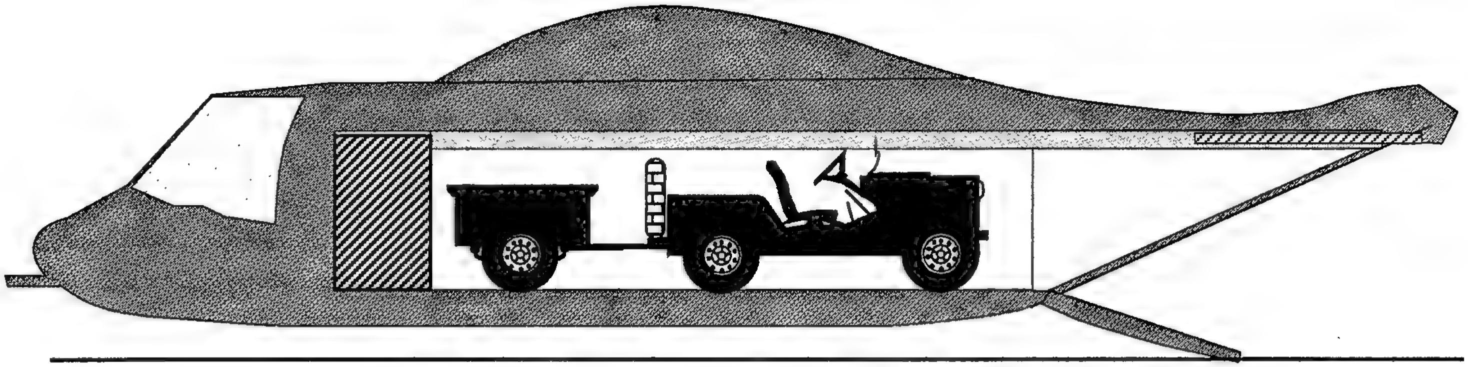
## V-22/RST-V Interface

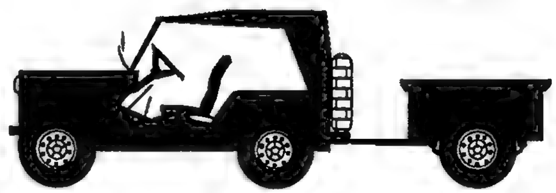
As part of the concept requirements process, additional data was gathered on the V-22/RST-V interfaces. The following figure shows the V-22 with a typical CH46 payload consisting of the M151A2 vehicle pulling an M416A1 1/4 ton trailer. The critical factor/assumptions used for this study are:

- Reducible width: 68 in. minus clearances of at least 1.5-2.0 in. per side = 64-65 in. (Ref. M151A2 = 63.7 in.).
- Max. length: 250 in. minus tiedown clearances (avionics rack) 12 in. = 238 in. (Ref. M151A2 w trailer = 238 in.).
- Reducible height: 65 in. minus roof mounted payloads and clearances 10 in. = 55 in. (Ref. M151A2 = 52 in.).
- Safety: Access/Egress of crew from rear of aircraft to forward section.
- Vehicle ramp breakover angle: 18.5 degrees.
- Crash restraint criteria (peace time): 16 g fwd & down, 10 g lateral, 5 g up & aft.

## Example RSTA Suite

The chart shows the Canadian LAV RECCE RSTA Suite. It provides a well documented notional baseline for a RSTA payload. Note that a complete trade study of the RST-V sensor suite is outside the scope of this study which is focused on the RST-V platform.





| | M151A2 1/4 TON VEHICLE | | M416A1 1/4 TON TRAILER | |
|---|---|---|---|---|
| Total Width | 63.7 In | > | 60.0 In | = 63.7 In |
| Total Length | 130.7 In | + | 107.25 In | = 238 In |
| Reducible Height | 52 In | > | 42 In | = 52 In |
| Curb Weight | 2435 Lbs | + | 568 Lbs | = 3003 Lbs |
| GVW | 3634 Lbs | + | 1318 Lbs | = 4952 Lbs |
| Payload Road | 1199 Lbs | + | 750 Lbs | = 1949 Lbs |
| Payload X-Country | 799 Lbs | + | 499 Lbs | = 1298 Lbs |

**M274 Mule (4x4)**

| | |
|---|---|
| Length | 116 In |
| Width | 69 In |
| GVW | 1826 Lbs |
| Payload | 999 Lbs |

# KEY EARLY TOP-DOWN TRADES

## ELECTRICAL POWER MANAGEMENT AND DRIVE ARCHITECTURE

Three basic electric power architectures were examined for RSTV
• full electric direct drive to motors in the chassis driving wheels through "axles"
• full electric direct drive to motors in the wheel hubs with energy storage treated as a separate subsystem inserted into the baseline direct electric power path
• full electric using energy storage as the power source to the motors with the engine/generator dedicated to "charging" the batteries

Modular flexibility for different RSTV configurations, elimination of mechanical complexity and the ability to easily power towed equipment combined to make the in-wheel motor drive appraoch the solution of choice. Concept designs, analysis and thorough review of potential weaknesses has confirmed the in-wheel drive to be superior and a low development risk.

The philosophy for achieving a hybrid electric drive exploiting optimization of engines and energy storage was resolved in favor of a direct drive baseline architecture augmented by energy storage. This approach offers several key benefits:

- graceful degradation
- modular ability to accommodate evolving battery and capacitor technology and reoptimize as required
- ability to develop RSTV at low risk, allowing system development to parallel battery/capacitor maturation rather than have one depend 100% on the other.

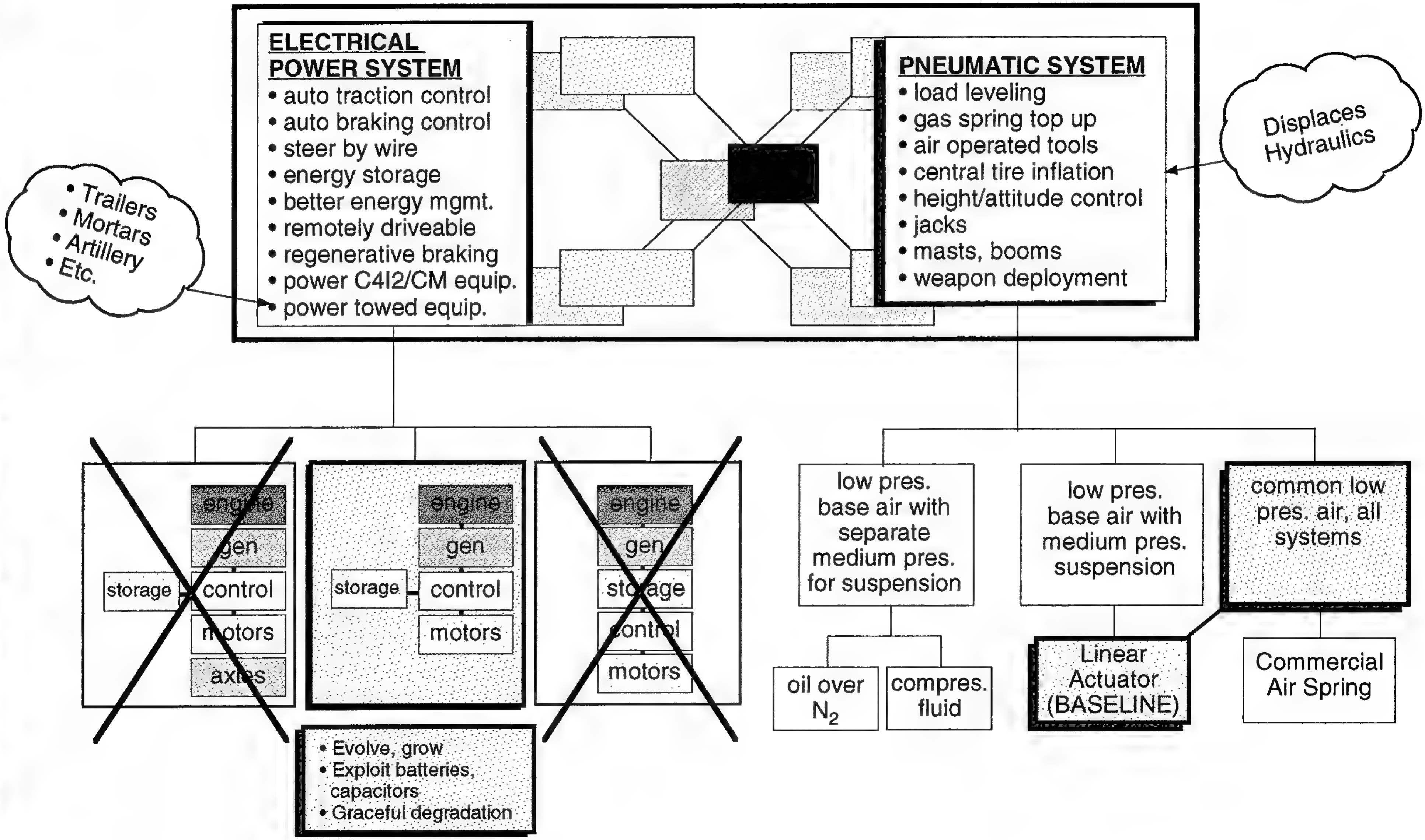
## PNEUMATIC SUSPENSION ARCHITECTURE

Based on previous experience with100 psi commercial air systems for high mobility vehicles, exploiting commercial-based pneumatic subsystems offer a wide range of benefits for the RSTV. However, early folding suspension concepts did not appear to allow such low pressures while retaining the narrow width objective. Air bags were to big around, and compact linear actuators required high, non-standard pressures.

Recent concepts have been developed that exploit dual cylinders of sufficient cross-section to keep air pressures below 100 psi while folding up into a 5 inch wide cavity. This break through allows us to proceed with development of a versatile air system architecture that can fully exploit commercial based products.

Because the air system pressure will be standard and low, and because the architecture can be made add or delete features in a modular fashion, development steps can be easily managed to fit schedule and/or cost constraints.

# KEY ARCHITECTURES FOR RSTV



## Concept Drawings and Characteristics

Select Comments:
The 4x4 concept was chosen as the baseline from the previous concept iteration. It is shown in the following charts with a notional RSTA suite based on the Canadian RECCE. While this concept fits in the V-22 via a folding suspension it still maintains the same wheel base and track as the HMMWV. Mobility is estimated to be superior to the HMMWV due to improved suspension characteristics and hybrid electric features. An important side benefit of the folding suspension is improved crew survivability against mine threats. This is a result of the tires extended out from the chassis when deployed for operation.

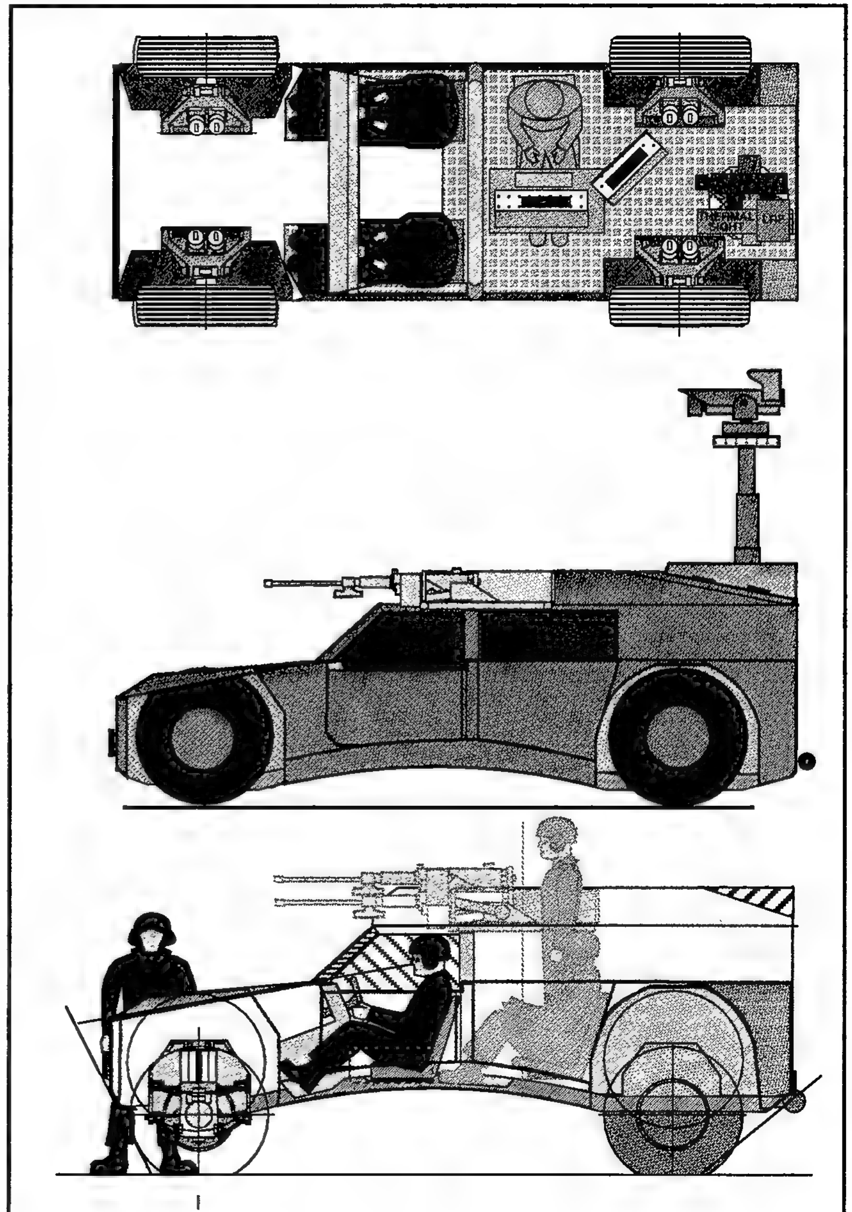
An important feature of hybrid electric drive is the flexibility to support powered trailers/towed payloads. The trailer concept shown utilizes the identical suspension and wheel drive systems as the prime mover. The use of the in wheel drives and advanced suspension design provides a low center of gravity for the empty trailer and permits the payload to ride low in the trailer thus further improving roll over stability. During the study several concepts for integrating the trailer were considered i.e. conventional pintle and clevis, four bar linkages and piano hinged with steering axle (Gamma Goat like). All options promise to greatly increase mobility and safety of the system over older designs. While the system GVW may exceed the recommended limits of the V-22, there remains many situations where increase towing/stowage capability is allowed and desired.

The 6x6 articulated RSTV concept was developed in an attempt to maximize use of the available volume in the V-22. Due to tip implication with V-22 ramp breakover angle (18.5 degrees) it became necessary to add a hinged joint to the middle of the vehicle. The articulation or hinged joint also becomes desirable for crossing natural and man made obstacle such as ditches, road berms and steps. An important goal of the concept was to design the front segment to accommodate the USMC missions with the rear segment detached. With the rear segment attached the goal was to provide the extra that might be required for extended missions such as specified by the SOCOM requirements.

Data is provided on the 6x6, 8x8 and tracked concepts for completeness.

# 4X4 BASELINE RSTV CONCEPT

- V-22 Compatible
- Cross Country Mobility > HMMWV
- Dash & Agility > HMMWV
- Stability (lower CG) > HMMWV
- Ground Clearence > HMMWV
  - Floorpan flat with no bumps
- VCI = HMMWV
- Mine Resistance > HMMWV
- 4-6 Seating
- 4 Side doors, 1 Rear door
- 3000 LB Payload @ 8000 LB GVW
- Height control
- Capable of other Variants
  - Light Strike Vehicle
  - Ambulance
  - Bn C2
  - Mortar
  - Anti-Tank (TOW, Javelin)
  - FOG-M
  - Air Defense (Stinger)



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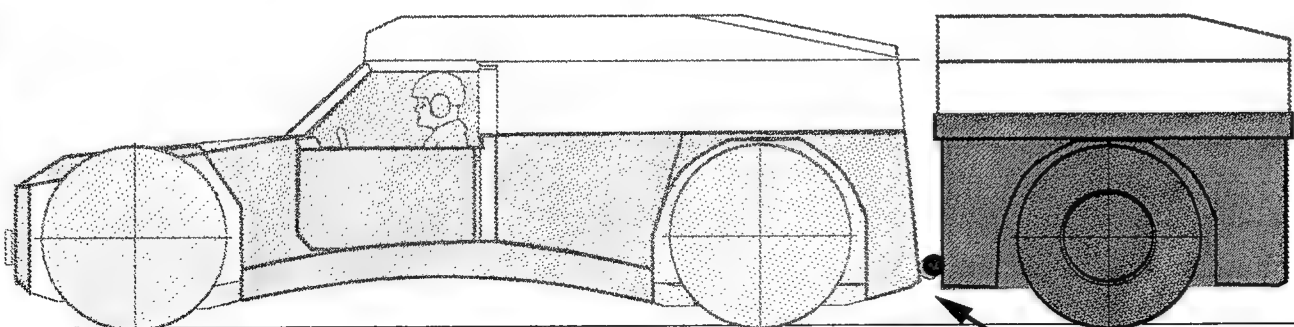
# RSTV POWERED TRAILER

**RSTV POWERED TRAILER**

- Employs same electric drive suspension units of RSTV
- Alternate hitch concepts
  - extendable damped tongue
  - "piano" hinge
  - extendable "piano" hinge
  - four bar link
- Low floor
- Low CG
- Height control inherent
- Optional electric steering

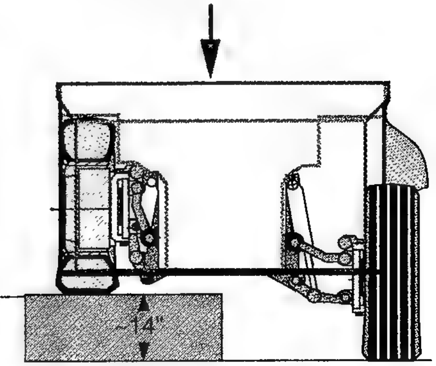
**RSTV POWERED TRAILER**

- When mission equipment exceed volume rather than weight available
- When mission will not require V-22 insertion
- When weight limit of 8400 lbs is waived for mission purposes



RSTV 4x4 concept in V-22 Insertion Mode

Trailer tongue retracted for V-22 insertion




END VIEW

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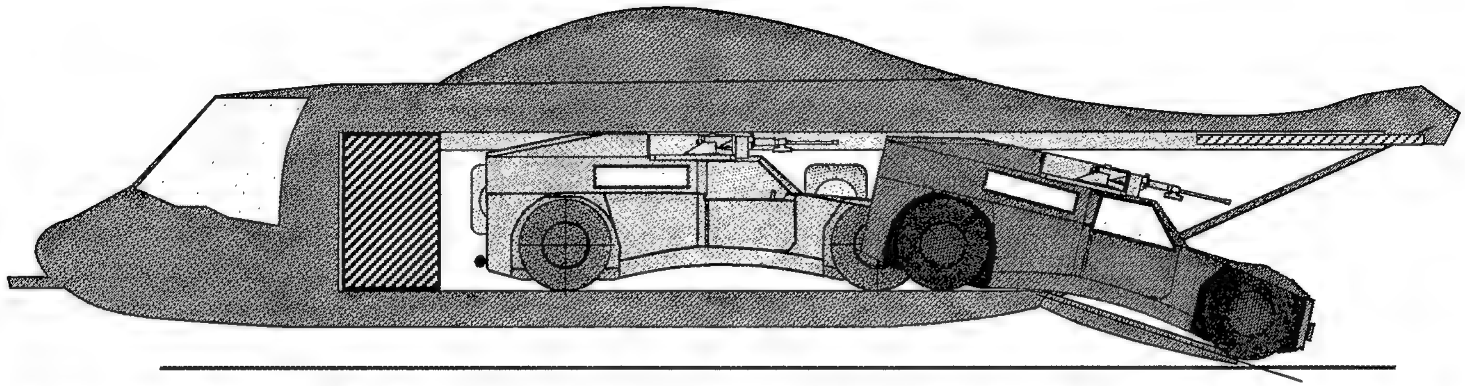
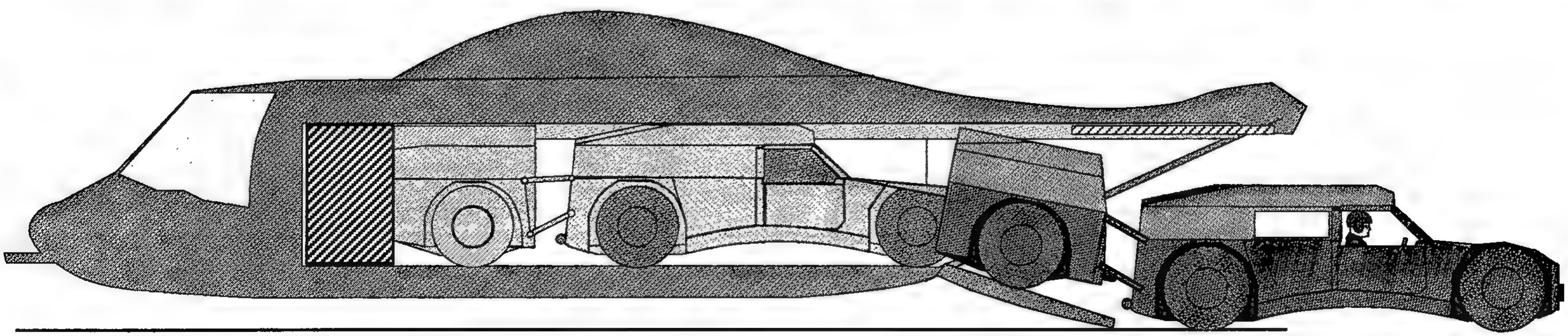
# 4X4 RSTV CONCEPT



# WITH ADVANCED POWERED TRAILER



# 4x4 Vehicle Objective Characteristics

| | | | |
|---|---|---|---|
| Seating: | 4-6 | Slope: | 60%/40% |
| Access doors | 4 side, 1 rear | Engine: | V8,190 hp, Diesel |
| Useable Volume: | 186 cu. ft. | Generator: | PM, 150 KW |
| Weight (Curb): | 5000 lb. | Traction Motors: | PM, 600 ft-lb |
| Payload: | 3000 lb. | Gearbox: | Single Speed, 5:1 |
| Length: | 190 in. | Tractive Effort: | 1.0 (2000 lb./wheel) |
| Width (Road/Transport): | 81.5 in./65 in. | Batteries: | 2, 6TL |
| Height (transport): | 55 in. | Capacitor: | 1 MJ, 16 f, ultra-cap |
| Ground Clearance: | 18 in. | Steering: | Rack/electric assist |
| VCI (35% Deflection): | 18 | Turning Radius: | 25 ft. |
| Track (Road): | 71.6 | Suspension Type: | Independent, air |
| Wheelbase: | 130 in. | Wheel Travel: | 10 in./3 in. |
| Approach/Departure: | 63/60 deg. | Tires: | 9.00R20 XL |
| Accel. (0-60 mph): | 10 sec. | Wheels: | 7 in., 2 pc, runflat |
| Max. Speed: | 75 mph | Brakes: | Regen. Electric/Mech. |
| Range (max): | 300 mi. | Electrical System | 28 v./350 v. max. |
| Range (silent): | 3 mi. | Pneumatic System | 120 PSI, CFM |
| Fuel Capacity: | 25 gals. | | |

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# 6X6 RSTV CONCEPT

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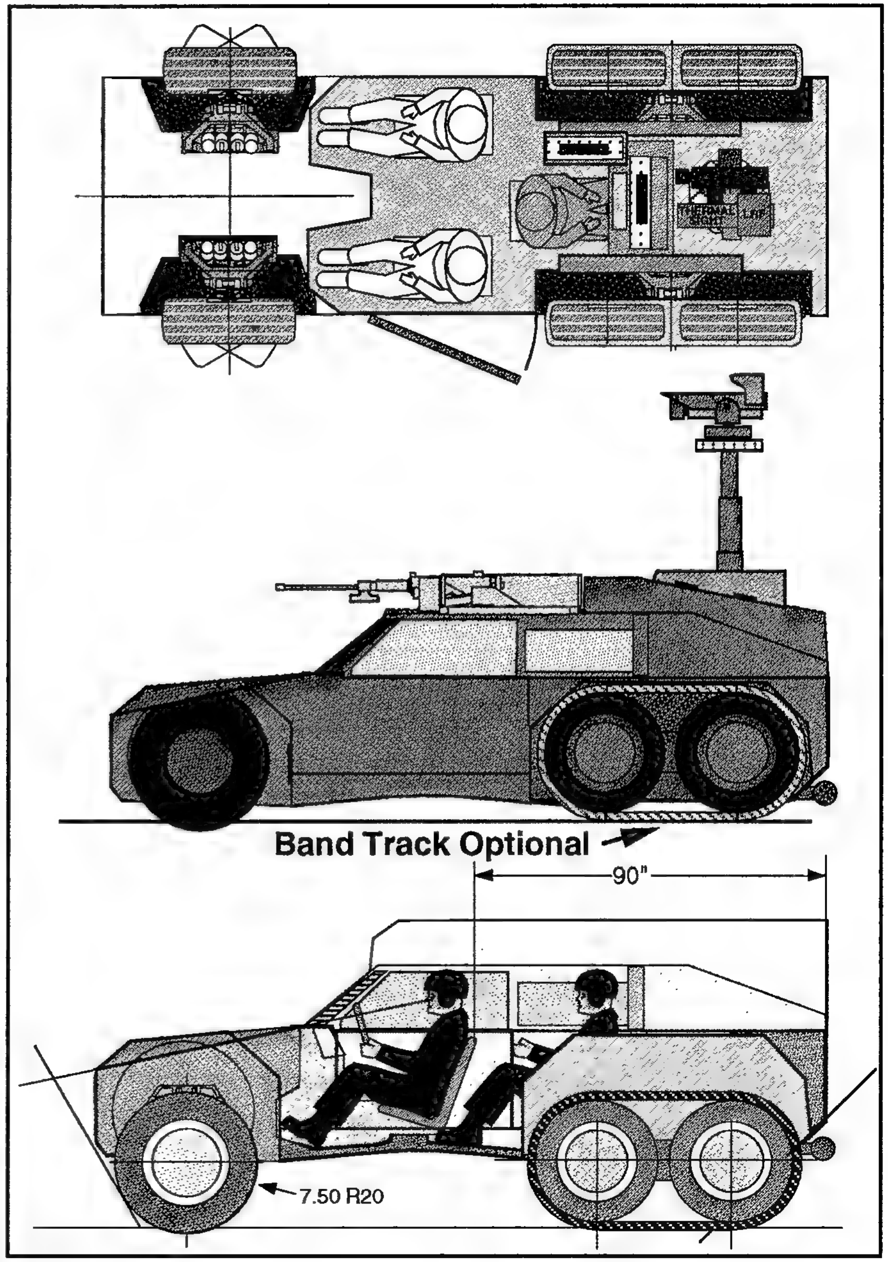
**OBJECTIVE: Increase mobility with tandem rear wheels and "band" track option.**

**PLUS against Baseline**
- **Better obstacle performance**
- **Better "Get Home Capability"**
- **Marginally better VCI**
- **Better traction**

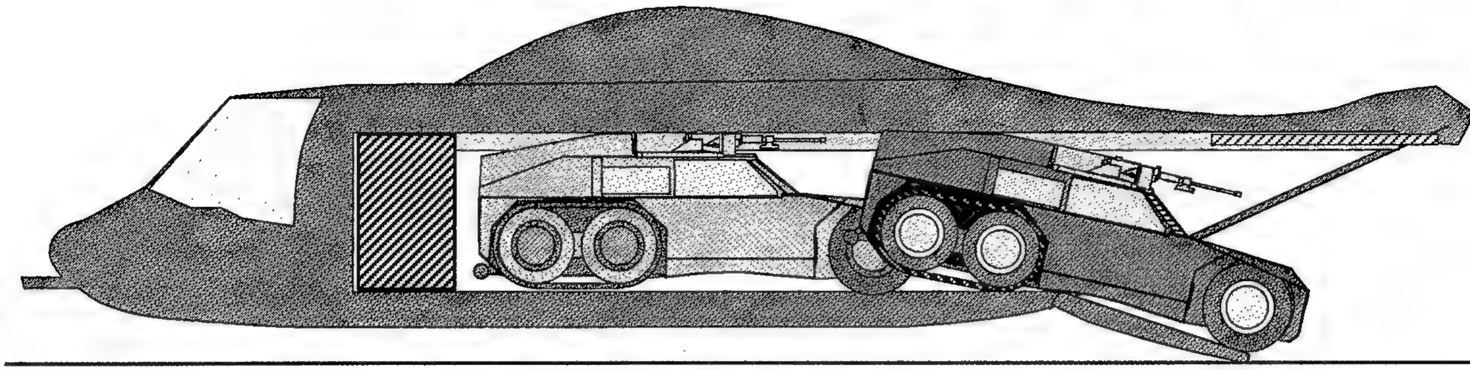
**MINUS against Baseline**
- **Poorer ride**
- **Poorer volume/utility**
- **Poorer ingress/egress**
- **Less cost efficient**
- **Less weight efficient**
- **Increased risk**

**(essentially a 4x4 with extra wheels and less volume)**

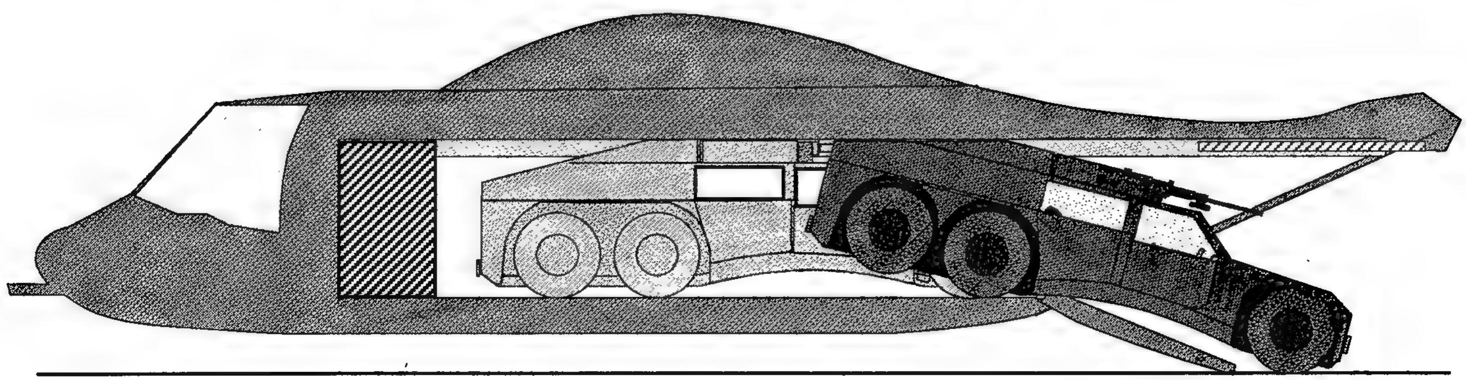
**COMMENT: Mobility analysis to date have not shown expected mobility gain with 6x6. Longer 6x6 variant solves access concern but cost & weight still a problem**



# 6X6 RSTV CONCEPT



# 6X6 STRETCH RSTV CONCEPT



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# 6x6 Vehicle Characteristics

| | | | |
|---|---|---|---|
| Seating: | 4 + 2 | Slope: | 60%/40% |
| Useable Volume: | 173 cu. ft. | Engine: | RPI 250 hp, Rotary |
| Weight (Curb): | 5146 lb. | Generator: | PM, 150 KW |
| Payload: | 2854 lb. | Traction Motors: | PM, 400 ft-lb |
| Length: | 190 in. | Gearbox: | Single Speed, 5:1 |
| Width (Road/Transport): | 81.5 in./65 in. | Tractive Effort: | 1.0 (1333 lb./wheel) |
| Height (transport): | 55 in. | Batteries: | 2, 6TL |
| Ground Clearance: | 18 in. | Capacitor: | 1 MJ, 16 f, ultra-cap |
| VCI (35% Deflection): | 17.5 | Steering: | Rack/electric assist |
| Track: | 71.6 | Turning Radius: | 25 ft. |
| Wheelbase: | 115 in. | Suspension Type: | Independent, air |
| Approach/Departure: | 63/60 deg. | Wheel Travel: | 10 in./3 in. |
| Accel. (0-60 mph): | 10 sec. | Tires: | 7.50R20 XL |
| Max. Speed: | 75 mph | Wheels: | 6 in., 2 pc, runflat |
| Range (max): | 300 mi. | Brakes: | Regen. Electric/Mech. |
| Range (silent): | 3 mi. | Electrical System | 28 v./350 v. max. |
| Fuel Capacity: | 25 gals. | Pneumatic System | 120 PSI, CTI, Hgt Cntl |

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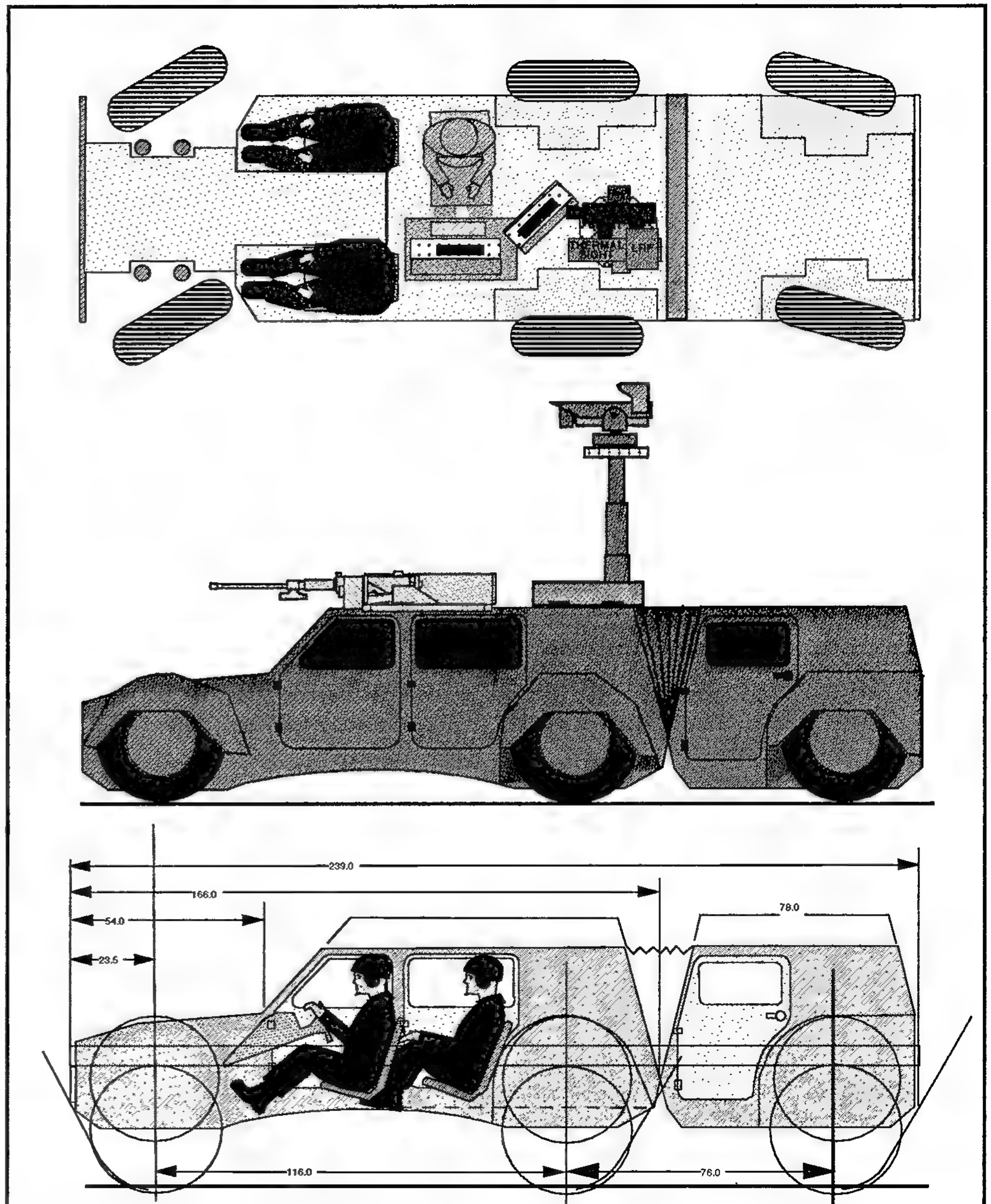
# 6X6 SEMI-ARTICULATED RSTV CONCEPT

**OBJECTIVE: Extend RSTV to better use V-22 volume. Articulate in pitch axis & exploit 6 wheel drive. Rear module to be detachable.**

**PLUS against Baseline**
- **Better obstacle performance**
- **Better VCI/tractive effort**
- **Better tractive effort**
- **Better "Get Home Capability"**
- **Better Ride**
- **Better Maneuverability**
- **Better volume/utility**
- **Better ingress/egress for 6**

**MINUS against Baseline**
- **Less cost efficient**
- **Less weight efficient (just meets 8400 lb limit)**
- **Increased risk**

**COMMENT: Need to verify adequacy of torsional resilience and best approach for pitch space.**



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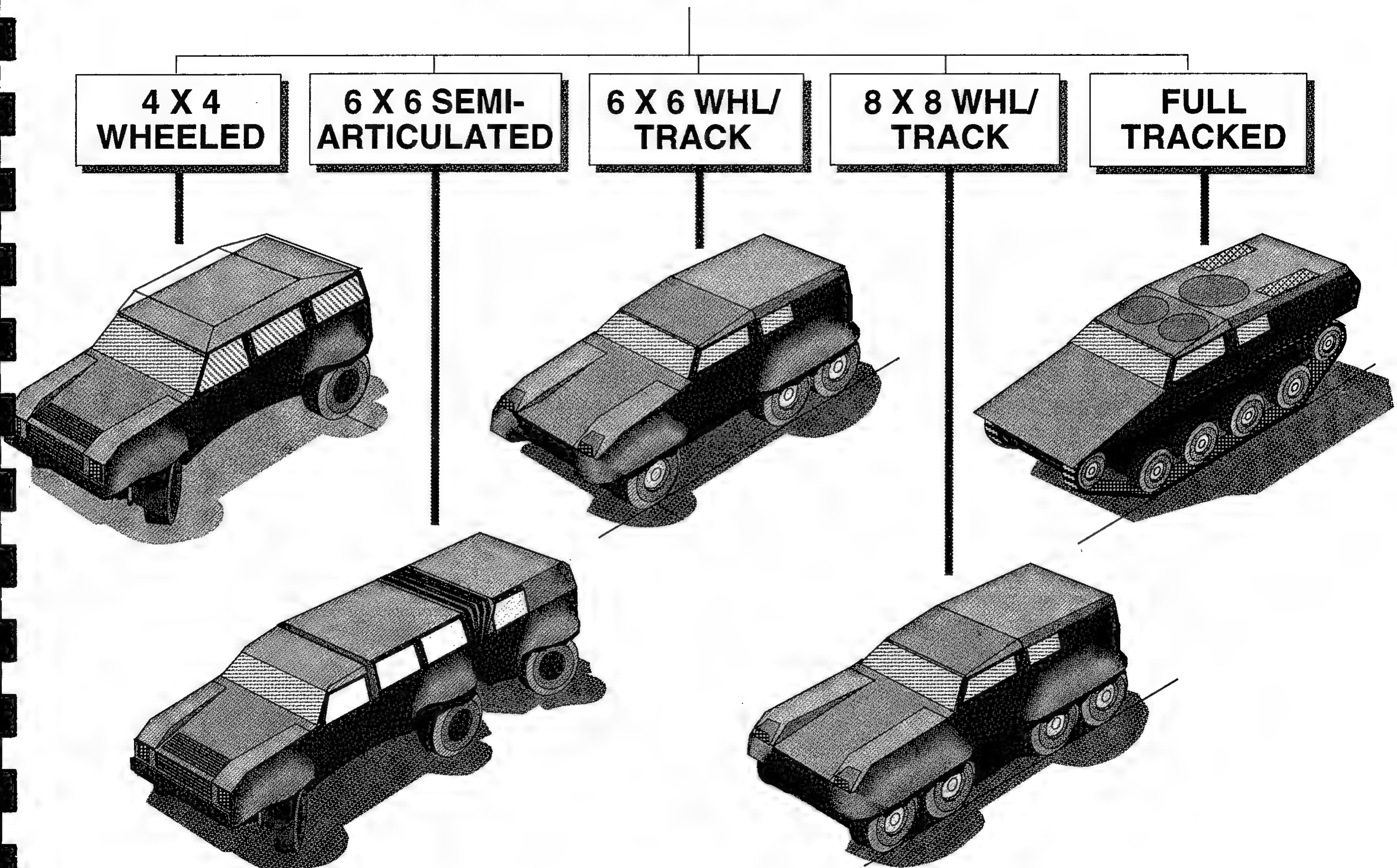
# RSTA-V Concept Tree



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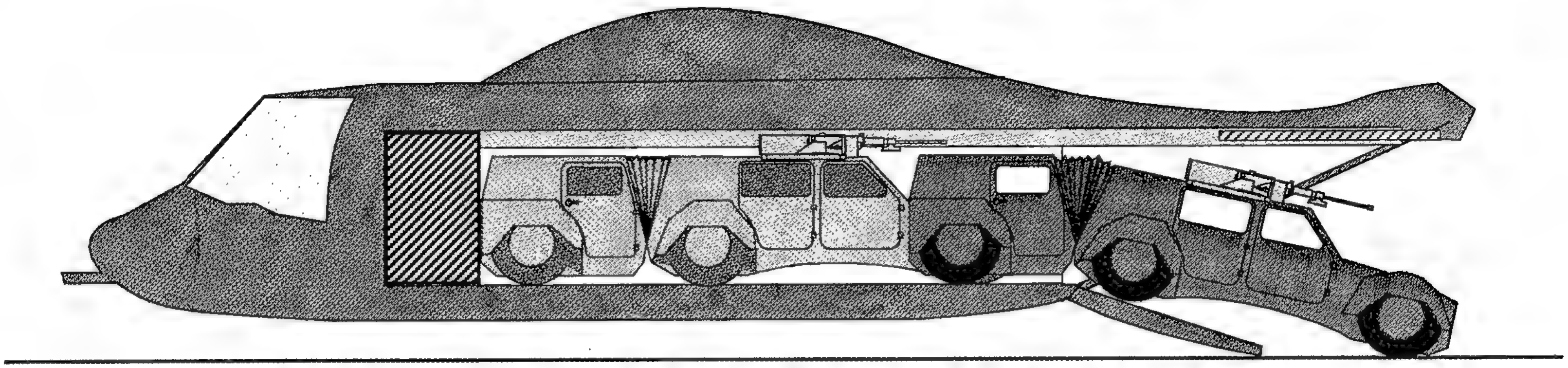
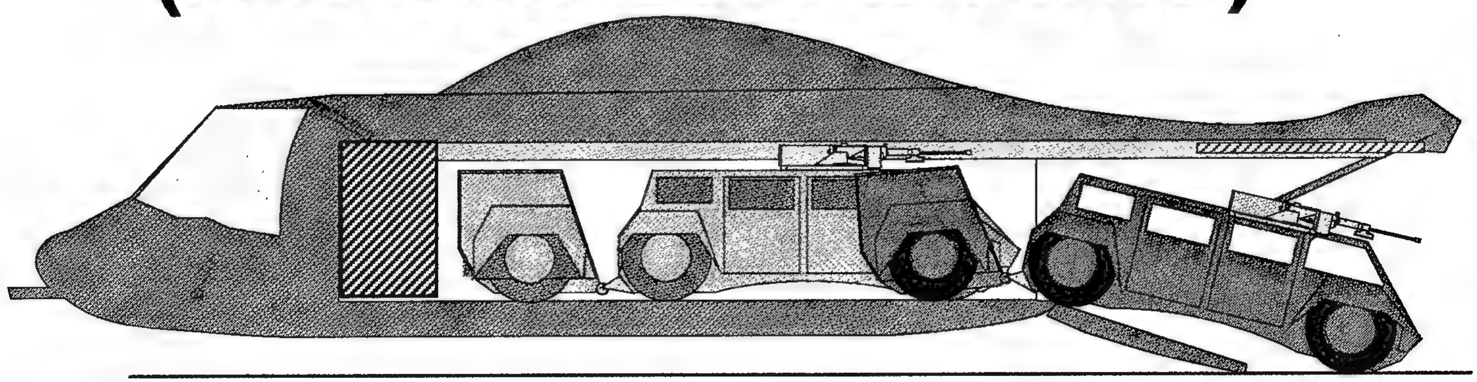
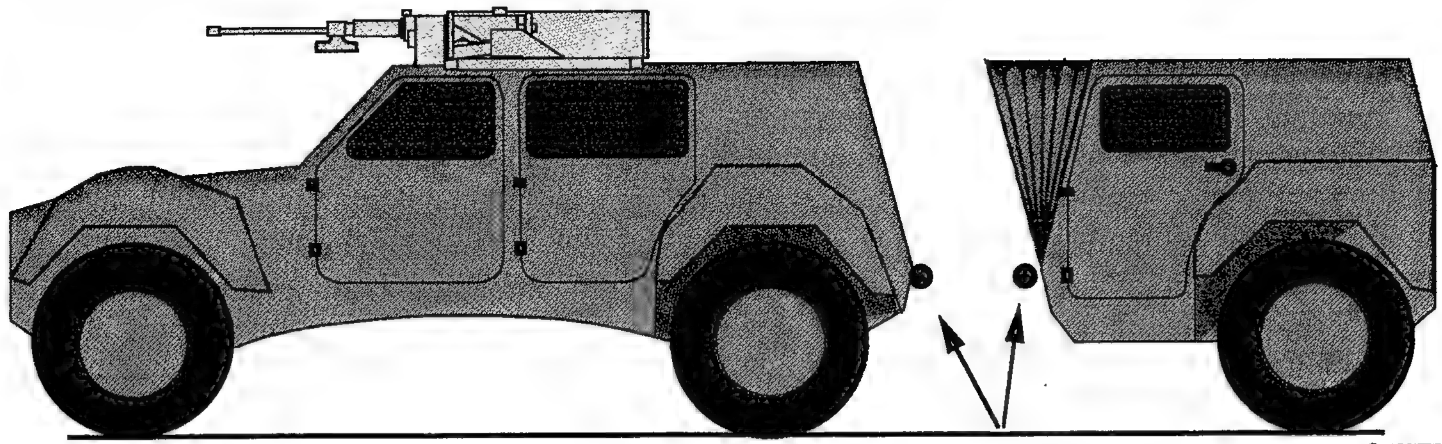
# 6X6 SEMI-ARTICULATED RSTV CONCEPT (FRONT ENGINE)



# (MID OR REAR ENGINE)



## USMC MISSION #1 | SOCOM MISSION #2



Pivoting joint consists of:
- Four pins
- Two quick release manifolds

| | | | |
|---|---|---|---|
| CURB WEIGHT | 4166 LBS | 1246 LBS | (5412 LBS) |
| PAYLOAD | 1500 LBS | 1500 LBS | (3000 LBS) |
| GVW | 5666 LBS | 2746 LBS | (8412 LBS) |
| VCI @ 35% DEFL. | 17.6 | | 18.3 |

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# 6x6A Vehicle Characteristics

| | | | |
|---|---|---|---|
| Seating: | 4 + 2 | Slope: | 60%/40% |
| Useable Volume: | 251 cu. ft. | Engine: | RPI 250 hp Rotary |
| Weight (Curb): | 5480 lb. | Generator: | PM, 150 KW |
| Payload: | 2520 lb. | Traction Motors: | PM, 400 ft-lb |
| Length: | 190 in. | Gearbox: | Single Speed, 5:1 |
| Width (Road/Transport): | 81.5 in./65 in. | Tractive Effort: | 1.0 (1333 lb./wheel) |
| Height (transport): | 55 in. | Batteries: | 2, 6TL |
| Ground Clearance: | 18 in. | Capacitor: | 1 MJ, 16 f, ultra-cap |
| VCI (35% Deflection): | 17.5 | Steering: | Rack/electric assist |
| Track: | 71.6 | Turning Radius: | 25 ft. |
| Wheelbase: | 116 in./76 in. | Suspension Type: | Independent, air |
| Approach/Departure: | 63/60 deg. | Wheel Travel: | 10 in./3 in. |
| Accel. (0-60 mph): | 10 sec. | Tires: | 7.50R20 XL |
| Max. Speed: | 75 mph | Wheels: | 6 in., 2 pc, runflat |
| Range (max): | 300 mi. | Brakes: | Regen. Electric/Mech. |
| Range (silent): | 3 mi. | Electrical System | 28 v./350 v. max. |
| Fuel Capacity: | 25 gals. | Pneumatic System | 120 PSI, CTI, Hgt Cntl |

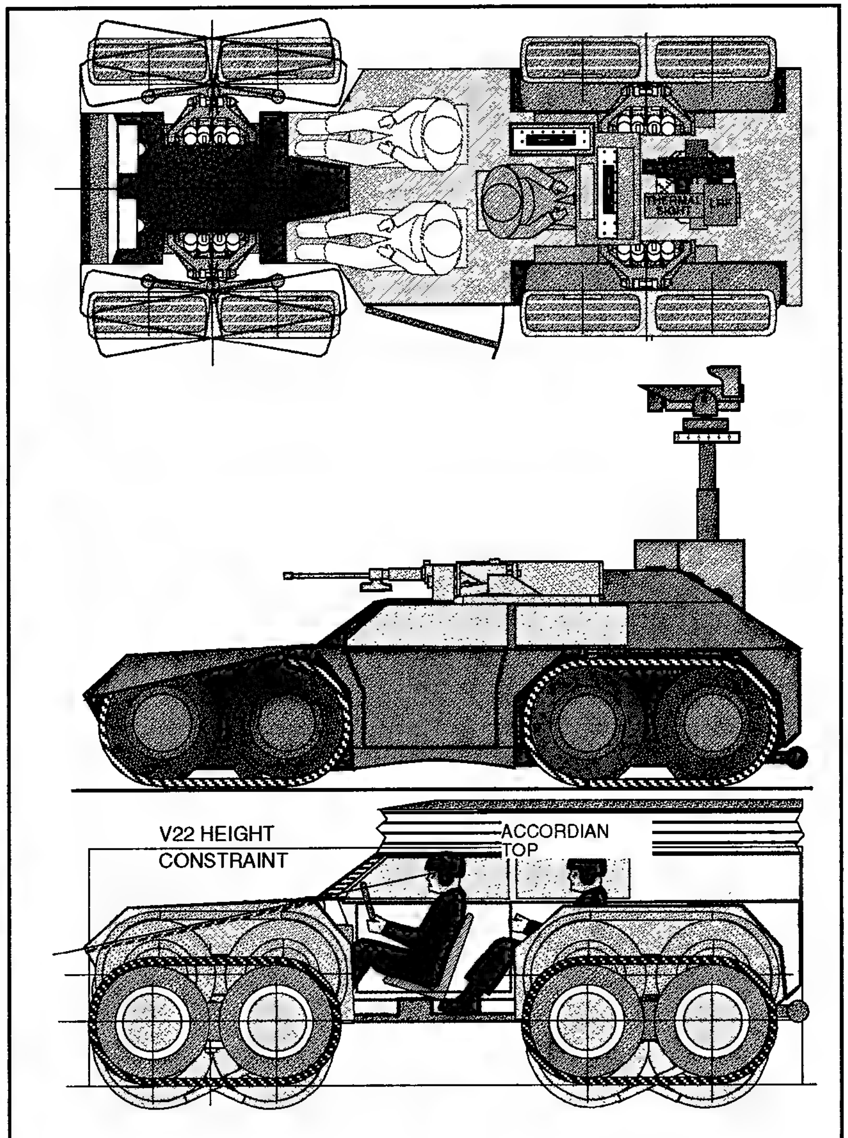
# 8X8 RSTV CONCEPT

**OBJECTIVE: Maximize wheeled mobility using 8x8 with band track option. Exploit wheel pairs and e-drive to achieve wheel & track steer benefits.**

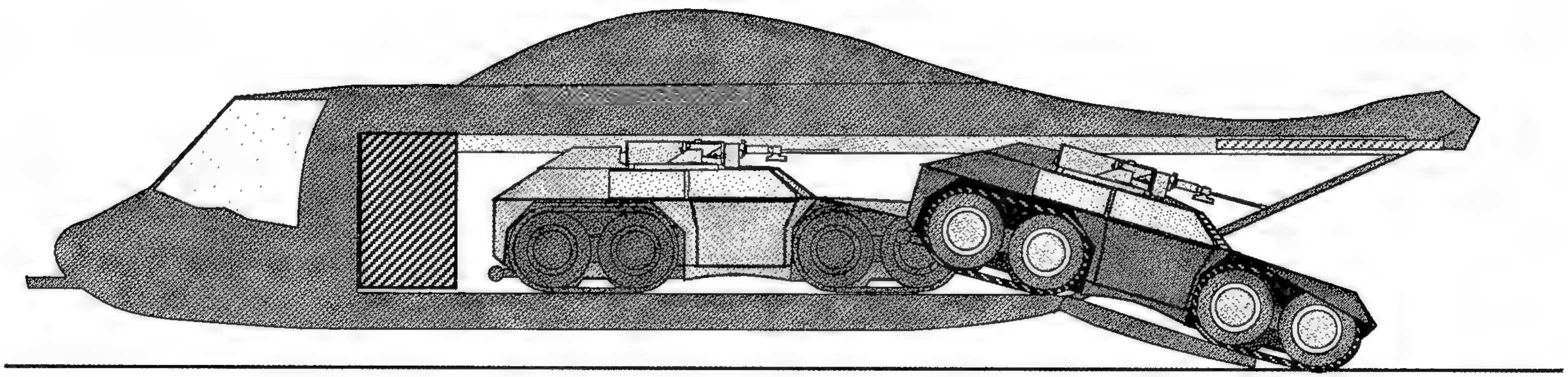
**PLUS against Baseline**
- **Better obstacle performance**
- **Better VCI/tractive effort**
- **Better ride (independent susp)**
- **Best "Get Home Capability"**

**MINUS against Baseline**
- **Poorer ride (walking beam susp)**
- **Less cost efficient**
- **Less volume/utility**
- **Poorer ingress/egress (2 side doors)**
- **Less weight efficient**
- **Exceeds mission/V-22 Weight**
- **More development risk**

**COMMENT: Tight band tracks have proven unacceptable. Tracks exist that can work. However, this concept does not down-size to RSTV constraints well. Weight & volume impacts to great. Better suited to 10-20 ton class.**



# 8X8 RSTV CONCEPT



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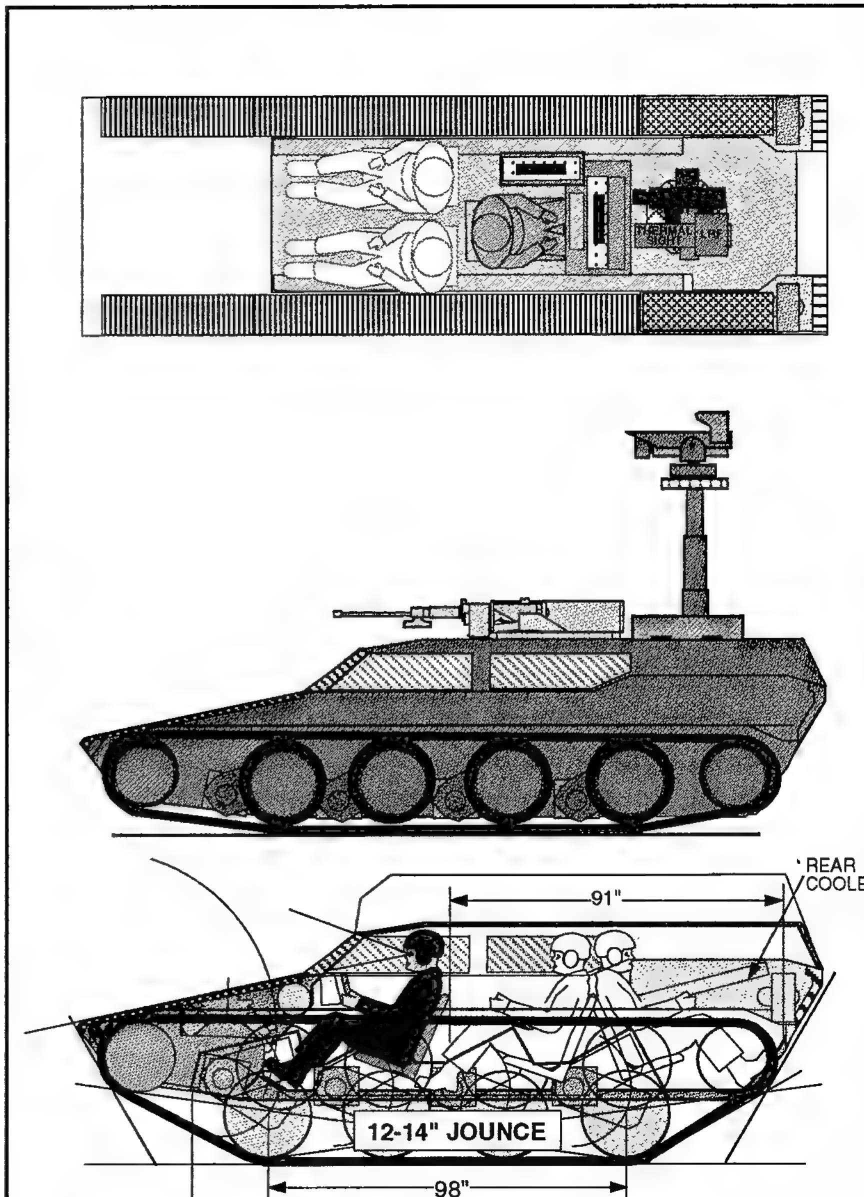
# TRACKED RSTV CONCEPT

**OBJECTIVE: Exploit tracks to achieve maximum possible all-terrain mobility**

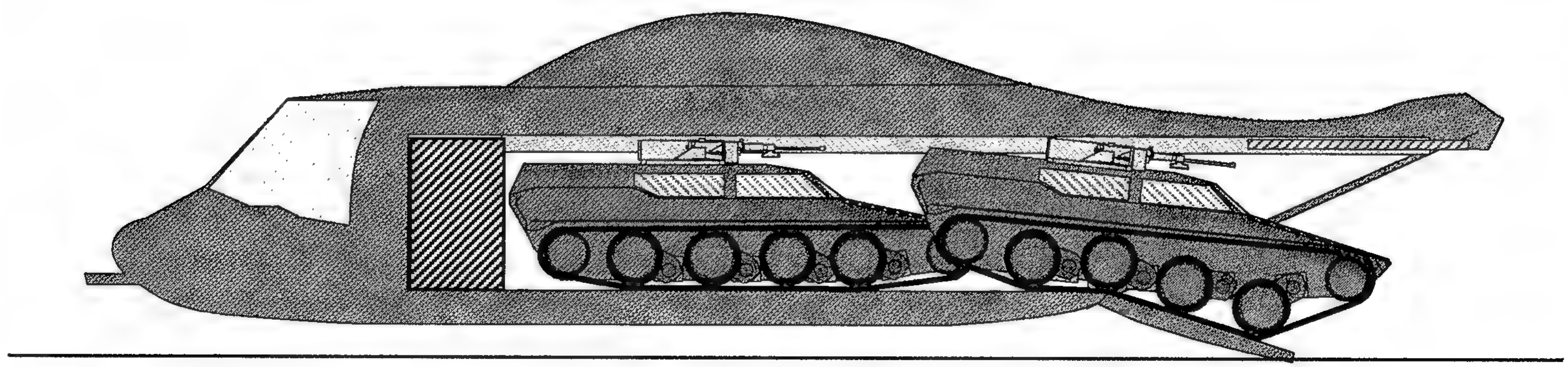
**PLUS against Baseline**
- Best obstacle performance
- Best VCI/tractive effort
- Best maneuverability
- Best cross country performance
- Best tractive effort
- Lower running gear vulnerability

**MINUS against Baseline**
- Worst roll stability (held to 65")
- Least cost efficient (prod & oper)
- Worst volume/utility (narrow)
- Worst ingress/egress (rear only)
- Lowest max. road speed
- Worst "Get Home Capability"

**COMMENT: Tracked mobility appears to greatly exceed RSTV needs. Combined with the narrow, limited access and unique development costs makes tracks poor solution for RSTV.**



# TRACKED RSTV CONCEPT



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# Tracked Vehicle Characteristics

- Seating: 4 + 2
- Useable Volume: 186 cu. ft.
- Weight (Curb): 5983 lb.
- Payload: 2017 lb.
- Length: 190 in.
- Width (Road/Transport): 81.5/65 in.
- Height (transport): 55 in.
- Ground Clearance: 18 in.
- VCI (35% Deflection): 13.7
- Track: 55
- Wheelbase: 98 in.
- Approach/Departure: 63/60 deg
- Accel. (0-60 mph): 10 sec.
- Max. Speed: 75 mph
- Range (max): 300 mi.
- Range (silent): 3 mi.
- Fuel Capacity: 25 gals.

| | |
|---|---|
| Slope: | 60%/40% |
| Engine: | RPI 250 hp Rotary |
| Generator: | PM, 150 KW |
| Traction Motors: | PM, 1200 ft-lb |
| Gearbox: | Single Speed, 5:1 |
| Tractive Effort: | 1.0 (4000 lb./Track) |
| Batteries: | 2, 6TL |
| Capacitor: | 1 MJ, 16 f, ultra-cap |
| Steering: | Pivot Steer |
| Turning Radius: | Pivot Steer |
| Suspension Type: | Independent, air |
| Wheel Travel: | 10 in./3 in. |
| Tires: | Band Track |
| Wheels: | Al. with rubber rim |
| Brakes: | Regen. Electric/Mech. |
| Electrical System | 28 v./350 v. max. |
| Pneumatic System | 120 PSI, CTI, Hgt Cntl |

## RSTV Concept Volume Comparison

Useable internal volume was a significant factor in ranking the mission utility of each concept. In order to evaluate the utility of each concepts, it was first necessary to assess the internal volume needs of the USMC and SOCOM missions. The preliminary RSTV Concept Volume Assessment compares the estimated useable internal volume of each concept with the estimated volume of the payload identified in the draft system specification and the on-board equipment (OBE). Note that the estimate does not include mission specific sensors and/or external mounted weapons. Those items were allocated to the available external volume above the vehicle but within the V-22 allowable envelope (65 inches minus 2 inches clearance minus vehicle reducible height = 8 inches available). Based on this assessment the 4x4 and 6x6A hold the best promise of meeting the volume requirements of the USMC and SOCOM missions.

Individual vehicle internal volume calculations are included in Appendix 2.

## RST-V Concept Volume Assessment (Prel.)

| | 4x4 | 6x6 | 6x6A | Tracked |
|---|---|---|---|---|
| **Available Volume** | 186.0 | 173.0 | 251.0 | 155.7 |
| Crew (4) | 120.0 | 120.0 | 120.0 | 120.0 |
| Crew Equipment (4) 60 lbs | 15.3 | 15.3 | 15.3 | 15.3 |
| Water (10 days) 50 gals | 9.0 | 9.0 | 9.0 | 9.0 |
| Ration (10 days) | 4.7 | 4.7 | 4.7 | 4.7 |
| Manpack commo gear (70 lbs) | 2.3 | 2.3 | 2.3 | 2.3 |
| Weapons (200 lbs) | 0.5 | 0.5 | 0.5 | 0.5 |
| Ammunition (350 lbs, 8 cans) | 2.1 | 2.1 | 2.1 | 2.1 |
| Material (40 lbs) | 2.0 | 2.0 | 2.0 | 2.0 |
| Additional Fuel (40 Gals) | 7.2 | 7.2 | 7.2 | 7.2 |
| **TOTAL - Payload** | 163.1 | 163.1 | 163.1 | 163.1 |
| **Total - OVE** | 15.3 | 15.3 | 15.3 | 15.3 |
| **Total - Volume Required** | 178.4 | 178.4 | 178.4 | 178.4 |
| **TOTAL - Excess** | 7.6 | -5.4 | 72.6 | -22.7 |

## Concept Weight Estimates

Preliminary weight estimates were prepared for each concept in accordance with the Government furnished WBS. This was an essential step in evaluating the payload capabilities of each concept due to the 8000 pound GVW limit imposed by the V-22. Note that the weight carrying capability of each concept is substantial higher (+2000 lb.) than that shown with the flight limit imposed. As part of the weight estimating effort, an On-board Equipment (OBE) list was prepared based in part on Government provided data.

The total vehicle weight estimates are provided for both engines under consideration. The payload available after subtracting the vehicle curb weight from the transport limit of 8000 pounds is provided at the bottom of chart. For reference purposes the HMMWV, HTMMP and JTEV with trailers were included in the table.

The main conclusion from this analyses that the 4x4 has the best ability to meet the 3000 lb. payload weight requirement and offers significantly better capability than the HTMMP and JTEV including trailers. In refining the selected Best Technical Approach (BTA), additional weight savings will be sought to restore a 5-10% weight management reserve for the ATD phase.

Detailed Concept Weight Estimates are included in Appendix 1.

# Concept Weight - Basis of Estimate

| WBS | Subsystem | Basis of Estimate |
|---|---|---|
| 1.02 | Hull Structure | Extrapolation based on HTMMP/JTEV, Tubular Frame with Fiberglass Body |
| 1.03 | Steering & Suspension | Suspension components - Engr. Est.<br>Tires - Actuals<br>Wheels - Engr. Est.<br>RunFlats - Hutchinson Est. |
| 1.04 | Engine | Engine - Actual<br>Other comonents - HMMWV Actuals |
| 1.05 | Automotive Drive Train | Magnet Motor (RFI) |
| 1.07 | Auxilary Sysems | Generator - Magnet Motor (RFI)<br>Capacitor - Maxwell Brochure<br>Batteries - Actuals<br>Other - Engr. Est. |
| 1.16 | On-board Equipment | GFI |

# OBE List

| ITEM | WEIGHT (lbs) |
|---|---|
| First Aid Kit | 1.6 |
| Mattox | 10.0 |
| Bore Saw | 3.0 |
| Hi Lift Come Along Jack | 10.0 |
| Vehicle Bag | 1.0 |
| Camouflage Net | 50.0 |
| Tow Rope/Strap | 4.0 |
| Jumper Cables | 2.0 |
| Tool Kit | 25.0 |
| Spare Parts | 25.0 |
| NBC/Chemical Alarm | 3.0 |
| Vehicle Manual | 1.0 |
| Fire Extinguisher and Mount | 5.5 |
| Radios (2) | 92.0 |
| GPS | 2.0 |
| PLRS Basic User Unit | 10.0 |
| POL | 11.0 |
| Gun Mount, 50 cal. | 70.0 |
| Shovel | 3.0 |
| Axe | 5.5 |
| TOTAL | 334.6 |

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# Concept Weight Summaries by WBS

| VEHICLE TYPE | 4X4 | 6X6 | 6X6 | 8X8 Art. | Tracked | HTMMP | JTEV | HMMWV |
|---|---|---|---|---|---|---|---|---|
| 1.0 VEHICLE | | | | | | | | |
| 1.01 INTG. & ASS'Y | - | - | - | - | - | - | - | - |
| 1.02 HULL | 1085 | 1085 | 1365 | 1085 | 1085 | 1131 | 1104 | 2008 |
| 1.03 SUSPENSION & STEERING | 1041 | 1242 | 1296 | 1491 | 2259 | 722 | 748 | 1331 |
| 1.04 ENGINE | 1184 | 1184 | 1184 | 1184 | 1184 | 1171 | 772 | 1419 |
| 1.05 AUTO. DRIVE TRAIN | 971 | 1165 | 1165 | 1368 | 985 | 478 | 480 | 1064 |
| 1.07 AUXILIARY SYSTEMS | 548 | 548 | 548 | 548 | 548 | 100 | 1096 | 327 |
| 1.16 ON BOARD EQUIPMENT | 335 | 335 | 335 | 335 | 335 | 335 | 335 | 335 |
| | | | | | | | | |
| TOTAL CURB WEIGHT (DIESEL) | 5164 | 5559 | 5893 | 6011 | 6396 | 3937 | 4535 | 6484 |
| | | | | | | | | |
| TOTAL CURB WEIGHT (ROTARY) | 4751 | 5146 | 5480 | 5598 | 5983 | N/A | N/A | N/A |
| | | | | | | | | |
| TOTAL WEIGHT w. ELEC. TRAILER | | | | | | 5237 | 5835 | |
| | | | | | | | | |
| TOTAL PAYLOAD * (8000 lb limit) | 3249 | 2854 | 2520 | 2402 | 2017 | 2263 | 1665 | 5016 |
| PAYLOAD W/O ELEC. TRAILER | | | | | | 1063 | 465 | |

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## RSTV Objective System Weight Strategy

| WBS | Subsystem Description | Baseline Lbs. | Obj. Sys. Lbs. | Target % | Rationale for Objective System Goal |
|---|---|---|---|---|---|
| 1.0 | Vehicle | | | | |
| 1.01 | Intregration & Ass'y | na | na | na | |
| 1.02 | Hull | 1,085 | 879 | 19.0% | Use of advanced structures integrating composites, reduce overall length |
| 1.03 | Suspension & Steering | 1,041 | 947 | 9.0% | Aluminum road arm forgings, road wheels, composite run flats/bead locks |
| 1.04 | Engine | 1,184 | 1,006 | 15.0% | Aluminun or nylon radiators and fuel tanks, lighter engines i.e. rotary or smaller diesel |
| 1.05 | Auto. Drive Train | 971 | 874 | 10.0% | Reduce tractive effort requirement of wheel motors from 1.0 to 0.8 |
| 1.07 | Auxiliary Systems | 548 | 466 | 15.0% | Lighter genrator housing, advanced batteries (lithium ion or NMH) |
| 1.16 | On-Board Equipment | 335 | 335 | | Needs further review |
| | | | | | |
| | Total Curb Weight (lbs.) | 5,164 | 4,507 | 12.7% | Target weight savings for 10% Reserve |

**Concept Selection**

Conclusions: The 4x4 concept offers the best mix of payload capacity, cost, risk, mobility and V-22 compatibility (weight).

Recommendation: Continue refinement/optimization of the 4x4 concept with emphasis on weight reduction, trailer/towed payload interfaces and subsystem refinement. Continue documentation of the preferred solution via Solid modeling and NRMM II analyses.

Selection Issues:
- User input on payload requirements and priorities.
- NRMMII Assessment/WES critique of the mobility characteristics.
- Weight management.
- V-22/RSTV interface assumptions.
- Demonstrator objectives and budget/affordability.

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# Concept Comparison Matrix

| | 4x4 | 6x6 | 6x6A | Track |
|---|---|---|---|---|
| Cost (LCC) | Lowest Cost | | | |
| Risk | Lowest Risk | | | Track Developement |
| V-22 Compatibility | Tie-downs - OK Lightest Weight | Tie-downs - OK | Tie-downs - OK ? | Tie-downs - OK Heaviest Weight |
| Mobility | | | | Best Ride Best OBS |
| Mission Utility | Good Volume Good Egress | Poor Volume Poor Egress | Best Volume Best Egress | Worst Volume Worst Egress |
| Survivability | | | Best Get Home Capability | Worst Get Home Capability |
| Safety | | | Must Address Pitch Joint? | |
| RAM/ Logistics | Fewest Parts | | | Track RAM Issues |

Arrows point towards improvement

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**Drive Motor Configuration Trade Study**

Objective: Select the preferred physical installation configuration of the traction drive motors.

Approach: Comparison of principle concepts demonstrated to date: in-board transaxle similar to the JTEV, in-board wheel drives similar to the Pentastar's Hybrid Electric HMMWV and the in-hub wheel drives similar to the Magnet Motor's wheeled vehicle test rigs.

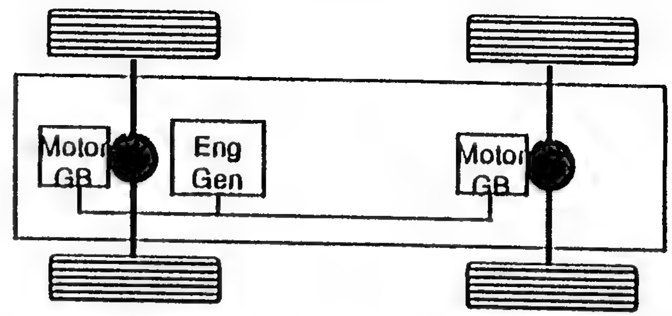
Conclusion: The In-hub Wheel Drive concept provides the best mobility, mission utility and maintainability features of the three concepts considered. It however presents the greatest design challenge and consequently the worst cost and schedule risk.

Recommendation: Recommend the ATD pursue the in-hub wheel drive approach with the fall back position being in-board wheel drive.

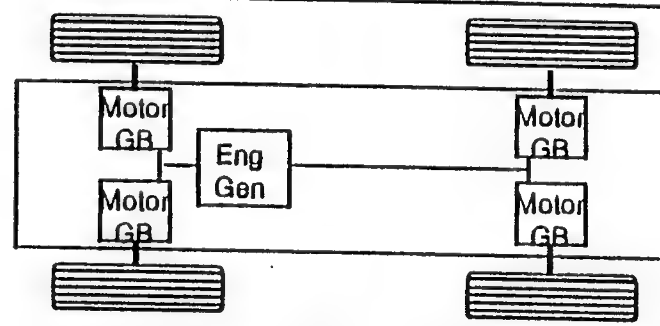
Issues: The remainder of the study should focus on developing a greater understanding of the In-hub wheel drive requirements, performance, weight and braking implications. Additional investigations should example the possibility of utilizing smaller rim diameter to facility compatibility with the larger commercial tire base.

# Drive Motor Configuration Concepts

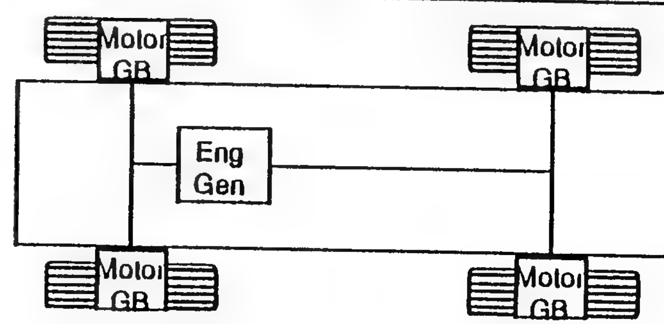
**In-Board Transaxle Drive Concept**
- Two Induction Motors, 36 hp (138 hp peak)
- Motor Torque/wheel 105 ft-lb
- Two 2 spd Gearboxs with Differential
- Gear Ratios with 2:1 Wheel End 20.9/41.8
- Tractive Effort: 0.75




**In-Board Wheel Drive Concept**
- Four PM Motors, 40 hp
- Motor Torque/Wheel: 250 ft-lb
- Four 1 Spd Gearboxes
- Gear Ratio with 2:1 Wheel End: 10.4:1
- Tractive Effort: 0.87




**In-Hub Wheel Drive Concept**
- Four PM Motors, 40 hp
- Motor Torque/wheel: 605 ft-lb
- Four 1 spd gearboxes
- Gear Ratio: 5:1
- Tractive Effort: 1.0

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# Drive Motor Configuration Assessment

| Criteria | In-board Transaxle | In-board Wheel Drive | In-hub Wheel Drive |
|---|---|---|---|
| **Cost (LCC)** | Lowest ATD Cost<br>Lowest Prod. Cost | ←<br>Highest Prod. Cost | Highest ATD Cost<br>Moderate Prod. Cost |
| **Risk** | Lowest Risk | ← | Highest Risk |
| **V-22 Compatibility** | Worst Interior Volume | → | Best Interior Volume |
| **Mobility** | Least Traction Control<br>Lowest Tractive Effort | →<br>→ | Best Traction Control<br>Highest Tractive Effort |
| **Mission Utility** | Worst Interior Volume | → | Best Interior Volume |
| **Survivability** | Highest Geartrain Noise | → | Lowest Geartrain Noise |
| **Safety** | Good H.V. Containment | Good H.V. Containment | H.V. Trans. to Wheels |
| **RAM/Logistics** | Difficult Accessibility | → | Good Modularity/Access. |

→ Points towards improvement

## MOBILITY

Mobility is best defined by how it is measured. These measurements fall into several broad performance categories. Those of primary interest for military vehicles are:

- Speed and acceleration,
- Stability,
- Ride quality,
- Off-road trafficability and obstacle negotiation.

Discussions of these mobility factors follow.

### Speed

Key speed and acceleration performance goals for the RSTA-V are presented in the following tables. Additionally, the tractive effort and power required by each of the operating conditions are tabulated. Rolling resistances of 1.5%, 10%, and 15% are assumed for hard surface, cross country, and dirt/sand conditions respectively.

Factors governing speed and acceleration are weight, available tractive power, grade, rolling resistance, and aerodynamic drag. For steady state speeds it is customary to determine the required tractive effort (TE) as a function of the other parameters. Then the product of the TE and vehicle speed is the required tractive power for that operating condition. TE is the force required to overcome the resistance to motion.

$$TE = Fr + Fg + Fa \ \text{lbs}$$

Where:
Fr = Rolling resistance, lbs
Fg = Grade resistance, lbs
Fa = Aerodynamic drag, lbs

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# RSTA-V Speed and Acceleration Issues

| Performance | Primary Issues | Draft Specification: Minimum | Draft Specification: Objective |
|---|---|---|---|
| Acceleration | Transient HP/Weight Ratio | 0 to 30 mph in 6 seconds<br>0 to 60 mph in 10 seconds | 0 to 30 mph in 4 seconds<br>0 to 60 mph in 15 seconds |
| Top Speed | Steady State HP/Weight Ratio | 60 mph | 75 mph |
| Dash Speed | Transient HP/Weight Ratio | 70 mph | 75 mph |
| Speed on Grade | Steady State HP/Weight Ratio | 40 mph on 5% grade<br>? mph on 60% grade | 60 mph on 5% grade<br>? mph on 60% grade |
| Reverse Speed | Steady State HP/Weight Ratio | | |
| Braking | Brake Capacity and Cooling | Hold on 60 % grade<br>20 mph to stop within 20 feet | |
| Ride Quality | Sprung and Unsprung Weights, Moment of Inertia, Suspension Stiffness and Damping, and CG and Crew Locations | Tabulated Absorbed Power and Acceleration Limits | |

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# RSTA-V Speed and Acceleration Key Operating Considerations

| Condition | Source | Duration | Speed (mph) | Grade (%) | Terrain | Tractive Horsepower | | Tractive Effort | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 8000 lb GVW | 6500 lb GVW | 8000 lb GVW | 6500 lb GVW |
| Cruising Speed - minimum | Draft Spec | Continuous | 60 | 0 | Hard Dry | 49 | 45 | 304 | 281 |
| Cruising Speed - objective | Draft Spec | Continuous | 75 | 0 | Hard Dry | 81 | 77 | 407 | 384 |
| Speed on Grade - minimum | Draft Spec | Continuous | 40 | 5 | Hard Dry | 64 | 54 | 601 | 504 |
| Speed on Grade - objective | Draft Spec | Continuous | 60 | 5 | Hard Dry | 112 | 97 | 703 | 606 |
| Minimum Gradability | Draft Spec | ? | 10 | 60 | Hard Dry | 113 | 92 | 4,241 | 3,447 |
| Dash Speed - minimum | Draft Spec | 10 min | 70 | 0 | Hard Dry | 69 | 65 | 370 | 347 |
| Dash Speed - objective | Draft Spec | 20 min | 75 | 0 | Hard Dry | 81 | 77 | 407 | 384 |
| Acceleration 0 to 30 mph - minimum | Draft Spec | 6 sec | 30 | 0 | Hard Dry | 91 | 74 | 5,600 | 4,550 |
| Acceleration 0 to 30 mph - objective | Draft Spec | 4 sec | 30 | 0 | Hard Dry | 139 | 113 | 5,600 | 4,550 |
| Acceleration 0 to 60 mph - minimum | Draft Spec | 15 sec | 60 | 0 | Hard Dry | 158 | 131 | 5,600 | 4,550 |
| Acceleration 0 to 60 mph - objective | Draft Spec | 10 sec | 60 | 0 | Hard Dry | 230 | 189 | 5,600 | 4,550 |
| Cross-country | Power Demand | Continuous | 15 | 0 | Dirt - Sand | 48 | 39 | 1,211 | 986 |
| Cross-country - Dash | Mission Profile | "Periodic" | 50 | 0 | X-country | 124 | 104 | 928 | 778 |
| Speed on Grade | Mission Profile | "Periodic" | 50 | 10 | Hard Dry | 139 | 116 | 1,044 | 872 |

Expanding these factors yields;

$$TE = (Cr \times Wt) + (Wt \times G/\mathrm{sqrt}(1+G)) + .00255 \times Cd \times A \times V^2$$

Where:
- Wt = gross vehicle weight, lbs
- Cr = coefficient of rolling resistance
- G = % grade/100
- Cd = coefficient of drag
- A = projected vehicle frontal area, ft^2
- V = vehicle speed, mph

Required tractive effort vs. speed curves for the notional RSTA-V on various grades are shown in the Tractive Effort Chart. The vehicle parameters are listed in the box on the chart. 1.5% rolling resistance is deemed appropriate for properly inflated radial tires on dry, hard asphalt pavement. This value would be somewhat lower on concrete and much higher on cross country terrain.

Lines of constant tractive horsepower are also shown. The points on the chart denote the "continuous" operating conditions listed in the Speed and Acceleration table. It is seen that the goal of 60 mph on a 5% grade requires 112 horsepower which is the highest continuous power. This power will provide a maximum speed in excess of 80 mph on level pavement which is greater than that required by the dash speed objective.

It should be noted that "tractive power" is that available at the drive wheels and does not include the drive train, electromechanical conversion, cooling, and other loses. Nor are any parasitic loads included. These are discussed in the section covering engine selection. The Performance table lists the estimated net tractive powers and maximum continuous vehicle speeds that might be anticipated from prime movers furnishing gross shaft horsepowers between 180 and 250 hp. Three conditions are considered. One with no auxiliary electrical power demand and the other two with power demands of 13 hp (10 kW) and 33 hp (25 kW) respectively.

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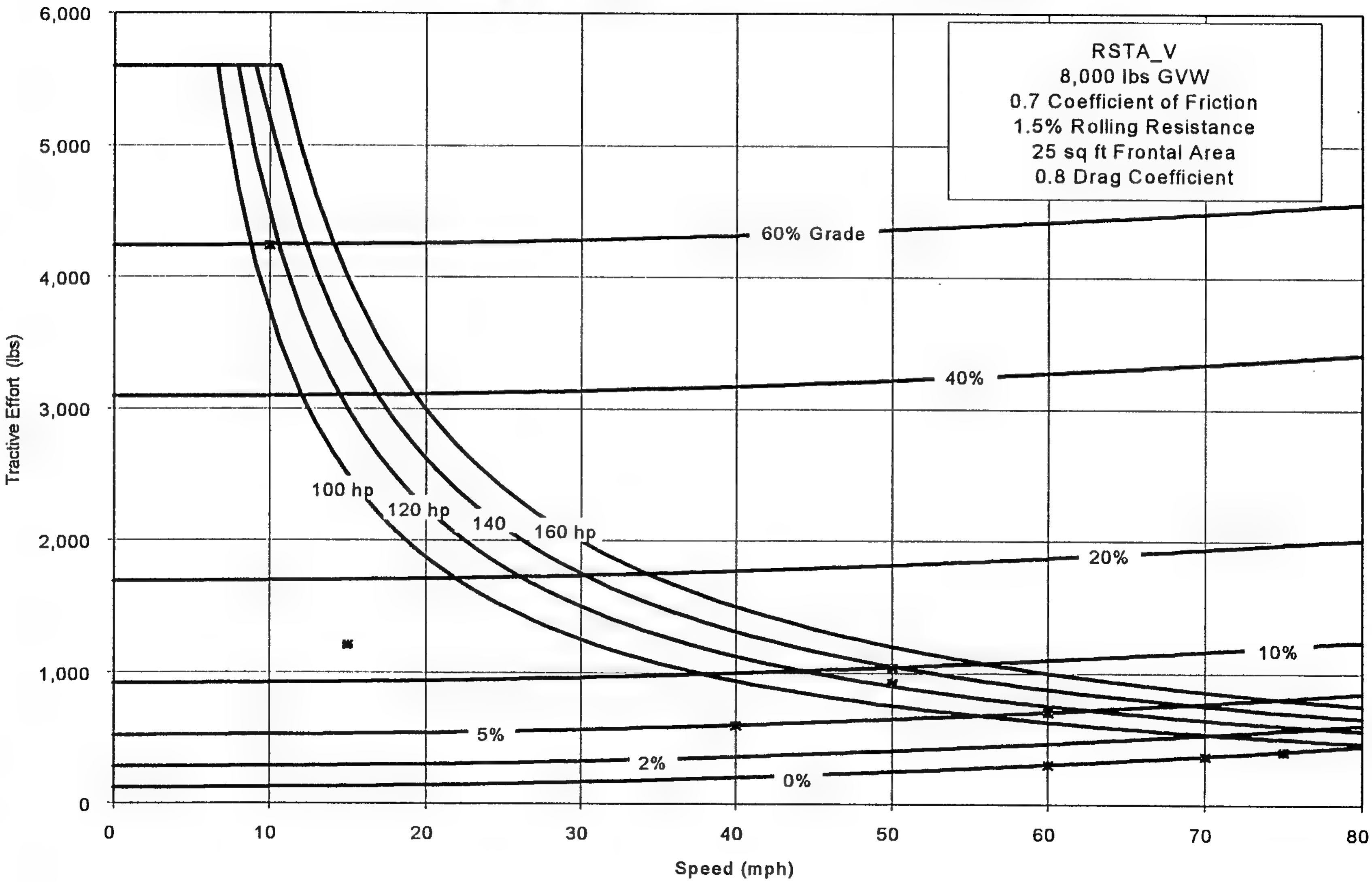
# RSTA-V Tractive Effort Chart



# Performance

| Item | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shaft Power | 180.000 | 190.000 | 200.000 | 250.000 | 180.000 | 190.000 | 200.000 | 250.000 | 180.000 | 190.000 | 200.000 | 250.000 |
| Cooling Fan | 45.000 | 45.000 | 45.000 | 45.000 | 45.000 | 45.000 | 45.000 | 45.000 | 45.000 | 45.000 | 45.000 | 45.000 |
| Power Steering | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 |
| Air Compressor | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 | 2.500 |
| Power to Generator | 130.000 | 140.000 | 150.000 | 200.000 | 130.000 | 140.000 | 150.000 | 200.000 | 130.000 | 140.000 | 150.000 | 200.000 |
| Generator Efficiency | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 |
| Power Conditioning Eff. | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 |
| Electrical Power Available | 118.315 | 127.416 | 136.517 | 182.023 | 118.315 | 127.416 | 136.517 | 182.023 | 118.315 | 127.416 | 136.517 | 182.023 |
| Power Demand | 0.000 | 0.000 | 0.000 | 0.000 | 13.000 | 13.000 | 13.000 | 13.000 | 33.000 | 33.000 | 33.000 | 33.000 |
| Power for Traction Motors | 118.315 | 127.416 | 136.517 | 182.023 | 105.315 | 114.416 | 123.517 | 169.023 | 85.315 | 94.416 | 103.517 | 149.023 |
| Motor Efficiency | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 | 0.954 |
| Final Drive Efficiency | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 |
| Tractive Power Available | 110.615 | 119.124 | 127.633 | 170.177 | 98.461 | 106.970 | 115.479 | 158.023 | 79.763 | 88.272 | 96.780 | 139.325 |
| Overall Efficiency | 0.851 | 0.851 | 0.851 | 0.851 | 0.851 | 0.851 | 0.851 | 0.851 | 0.851 | 0.851 | 0.851 | 0.851 |
| Max Speeds - mph | | | | | | | | | | | | |
| Hard Surface, 0% Grade | >80 | >80 | >80 | >80 | >80 | >80 | >80 | >80 | 75 | 78 | >80 | >80 |
| Hard Surface, 5% Grade | 59 | 62 | 65 | 77 | 55 | 58 | 61 | 74 | 47 | 51 | 54 | 69 |
| Hard Surface, 10% Grade | 41 | 44 | 47 | 58 | 37 | 40 | 43 | 55 | 31 | 24 | 36 | 50 |
| Hard Surface, 60% Grade | 9.8 | 10.5 | 11.3 | 15.0 | 9.0 | 9.5 | 10.0 | 14.0 | 7.0 | 8.0 | 8.5 | 12.5 |
| Cross-country, 0% Grade | 46 | 49 | 51 | 63 | 42 | 45 | 47 | 60 | 35 | 38 | 41 | 55 |

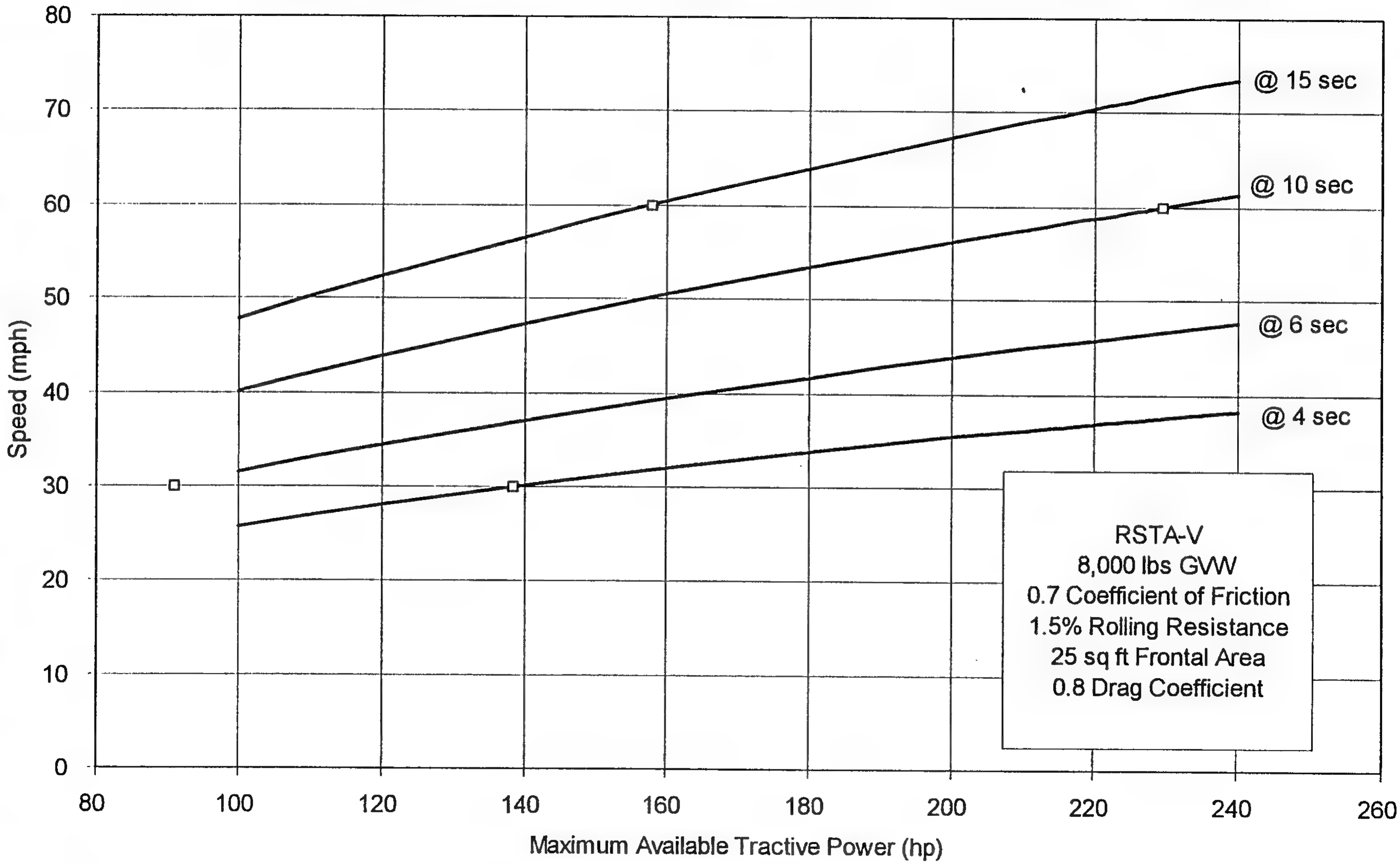
## Acceleration

The calculations for acceleration are more complex. During acceleration, the available tractive power from a mechanical drive system varies with vehicle speed depending upon the converter/transmission characteristics and shift points and the power vs. speed of the engine. Consequently a point design for the power train is required to accurately predict vehicle acceleration. Fortunately, in a hybrid system, the power output of the drive motors is nearly independent of output speed, or can be made so. Thus, the power can be considered constant over the speed range of interest enabling prediction of the acceleration without detailed knowledge of the drivetrain characteristics.

Accelerations were calculated assuming constant tractive power except at start-up where the tractive effort was set to an adhesion limit provided by 0.7 coefficient of friction. The two charts that follow show the speeds and distances attained by the notional RSTA-V for selected times vs. tractive power. The points shown on the speed chart correspond to the acceleration goals listed previously in the Key Operating Considerations table. With the exception of 0 to 30 mph in 4 seconds which requires only 91 hp, all of the acceleration goals require in excess of 112 tractive horsepower. This means that stored energy will be required to meet these and the other transient performance goals. Since the amount of energy stored and the storage medium are dependent upon the magnitude and duration of the transient power demand, a detailed definition of the term, "periodic," used in the Mission Profile is essential.

The amount of energy stored and the method of energy storage are topics of later discussions.

# RSTA-V Acceleration Speed vs. Tractive Power



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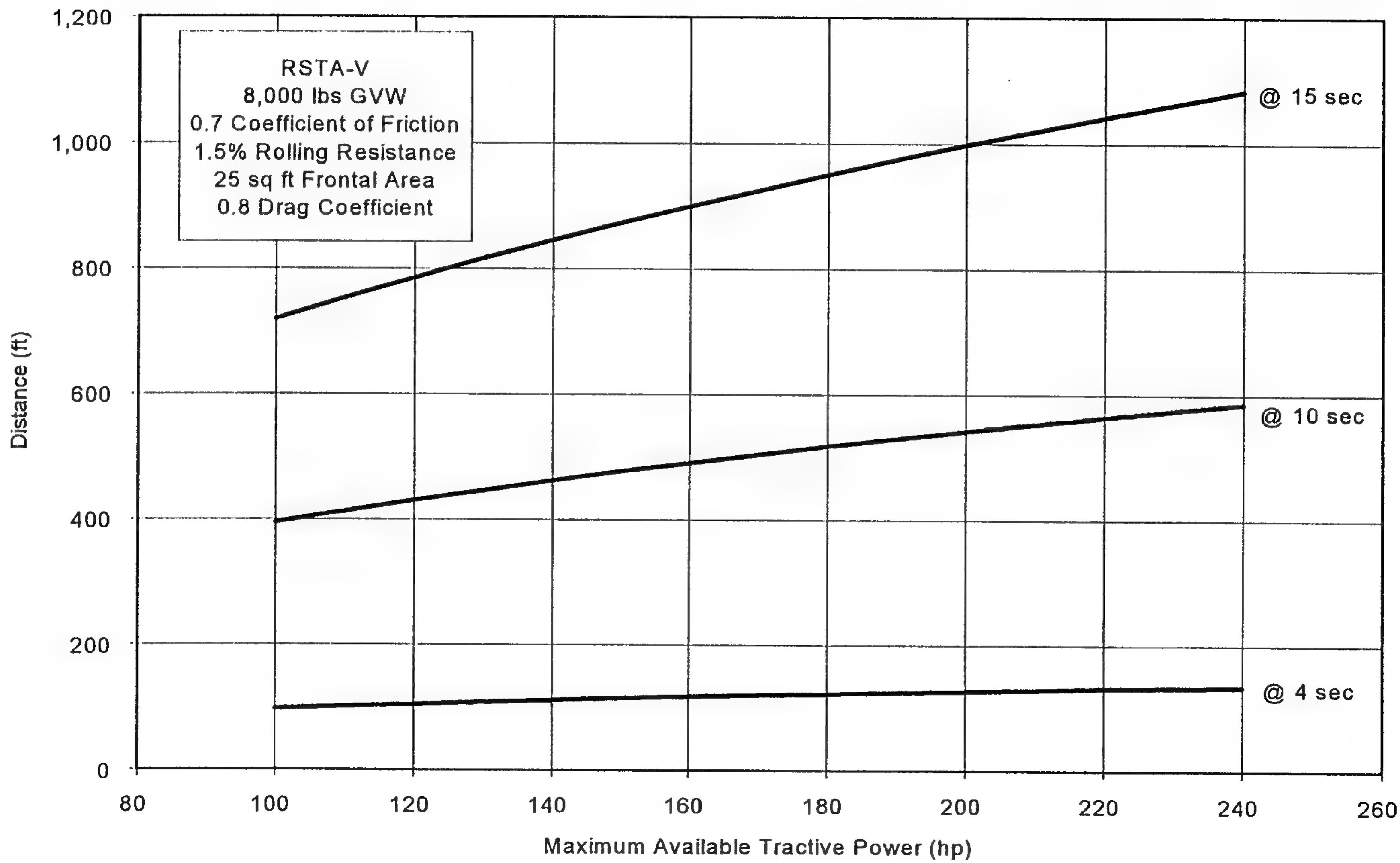
# RSTA-V Acceleration Distance vs. Tractive Power



**Stability**

The lateral stability requirements are outlined in the Stability and Obstacles table.

The two most important factors governing lateral stability are wheel track (t) and center of gravity height (h). t/2h has been defined as the "rollover threshold" and represents the lateral G force that a vehicle with a rigid suspension can sustain without rolling over. Analysis of accidents in which rollover was a factor shows a direct correlation between rollover threshold and accident rates. The Automotive Rollover Experience chart presents a summary of accident rates vs. rollover threshold. The rates have been normalized to those expected for GDLS' RSTA-V concept. The circles depict actual data points and the rectangles represent expected rates for the military vehicles noted. The curve was adapted from data reported by L. S. Robertson and A. B. Kelley, "Static Stability as a Predictor of Overturn in Fatal Motor Vehicle Crashes," in the *Journal of Trauma*, Vol. 29, No. 3, 1988, pp. 313-319

Roll stiffness is a somewhat lesser factor in vehicle lateral stability. The lower the roll stiffness the lower will be the lateral G force at rollover. The roll stiffness in degrees/G depends on the vehicle mass, cg height, roll center height, suspension stiffness, and the effective distance between springs. Most of these factors can not be determined without a point design. Fortunately, the mass and suspension stiffness can be related to one another by the bounce frequency of the vehicle, i. e., f = sqrt(k/M)/2Pi, and this can be used as a parameter in estimating roll stiffness. The bounce frequencies of wheeled vehicles usually fall in the range of 1.0 to 1.5 Hz. For an independent suspension with equal parallel upper and lower control arms, the roll center is at ground height and the effective distance between springs is the wheel track.

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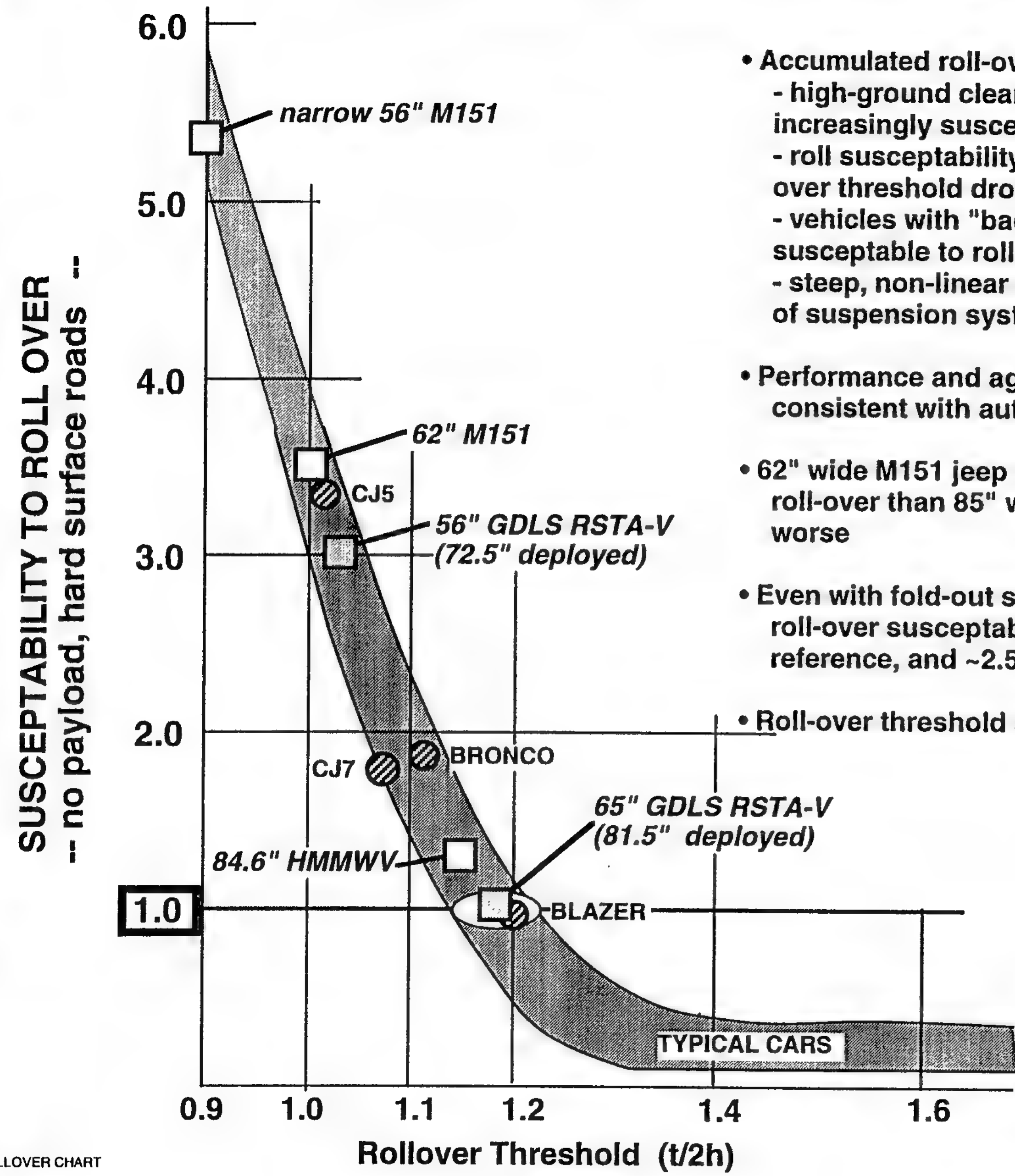
# RSTA-V Mobility Considerations
# Stability and Obstacles

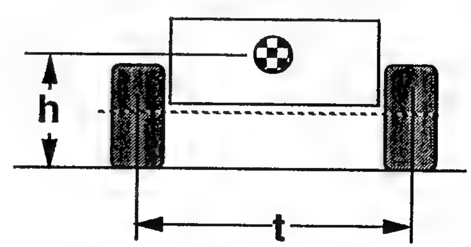
| | Performance | Primary Issues | Draft Specification | |
|---|---|---|---|---|
| | | | Minimum | Objective |
| ♑ | Step Climbing | Geometry, Tractive Effort, Braking, Tire Diameter and Aggressiveness, All-wheel Drive, Suspension, CG Location | 15 inch high vertical step in both forward and reverse directions. | 18 inch high vertical step in both forward and reverse directions. |
| | Gap Crossing | Same as above. | Not addressed | |
| | Obstacle Negotiation | Same as above. | Implied in NRMM Requirements | |
| ♑ | Stability - Longitudinal Slope | Same as above + Lubrication. | 60% grade - up and down | |
| ♑ | - Lateral Slope | Same as above. | 40% side slope @ 15 mph | 40% side slope @ 25 mph |
| | - Turning | Same as above. | 0.6 g lateral acceleration with less than 5 deg roll | |
| | Drawbar Pull | Tractive Effort, Tire Aggressiveness | 0.4 GVW on 200 RCI after 0.5 in/hr for 2 hours | |
| | Maximum Drawbar Pull - Cooling Point | Tractive Effort, Cooling | Not addressed – usually 0.7 GVW continuous on 120 F day | |
| ♑ | Shock Load | Ride Dynamics | Addressed under trafficability | |
| ♑ | Shock Load | Structure | Not Specified – we use AMCP 706-357 | |
| | | | | |

# ACCUMULATED AUTOMOTIVE EXPERIENCE VALIDATES ROLL-OVER CONCERNS

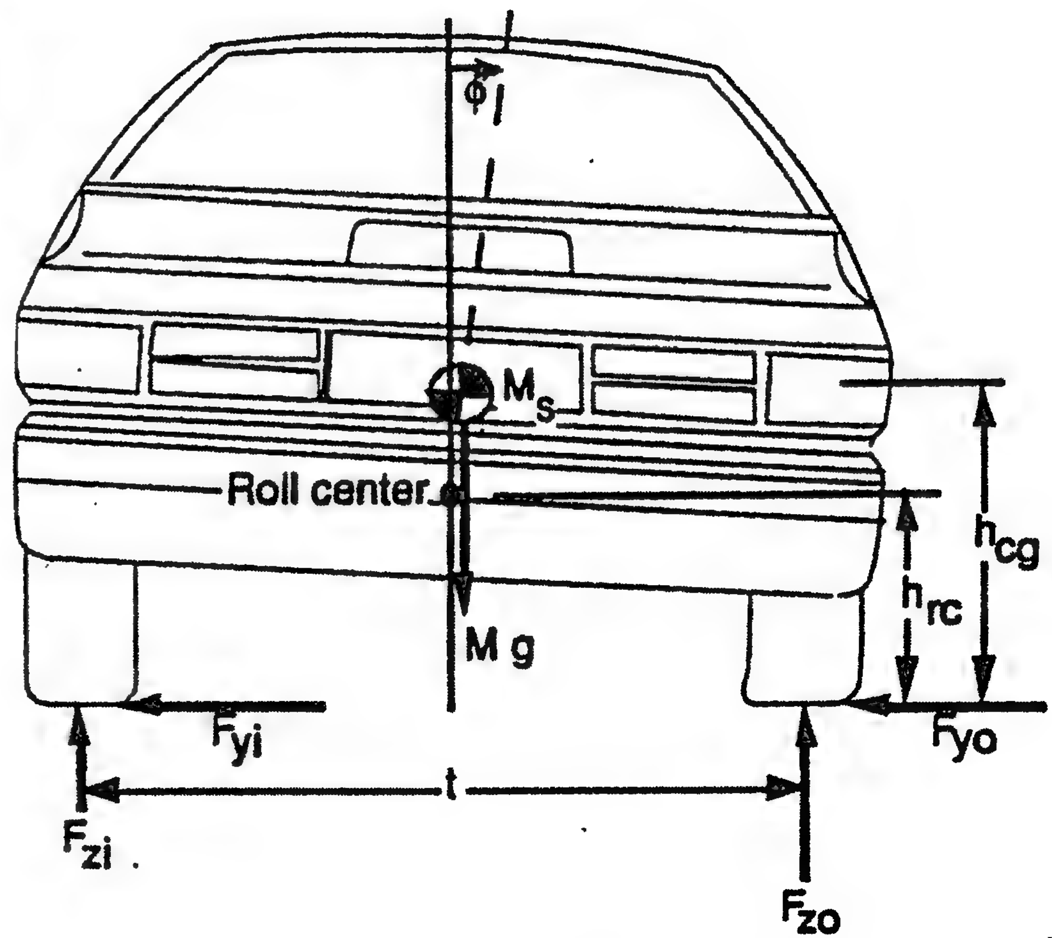



- Accumulated roll-over incidents confirm that
  - high-ground clearance vehicles with narrow tracks are increasingly susceptable to roll-over
  - roll susceptability increases dramatically when roll-over threshold drops below 1.2
  - vehicles with "bad" reputations are in fact very susceptable to roll-over (e.g., CJ5 jeep,M151 jeep)
  - steep, non-linear trend generally applies independent of suspension system designs
- Performance and agility objectives for RSTA-V are consistent with automotive data base
- 62" wide M151 jeep is about 3 times more susceptable to roll-over than 85" wide HMMWV--56" wide jeep is 4 times worse
- Even with fold-out suspension deployed, 56" wide RSTA-V roll-over susceptability will be 3 times worse than Blazer reference, and ~2.5 times worse than HMMWV
- Roll-over threshold should not be less than HMMWV (1.15)

note: modern high-mobility vehicles all have similar centers of gravity



# RSTA-V LATERAL STABILITY



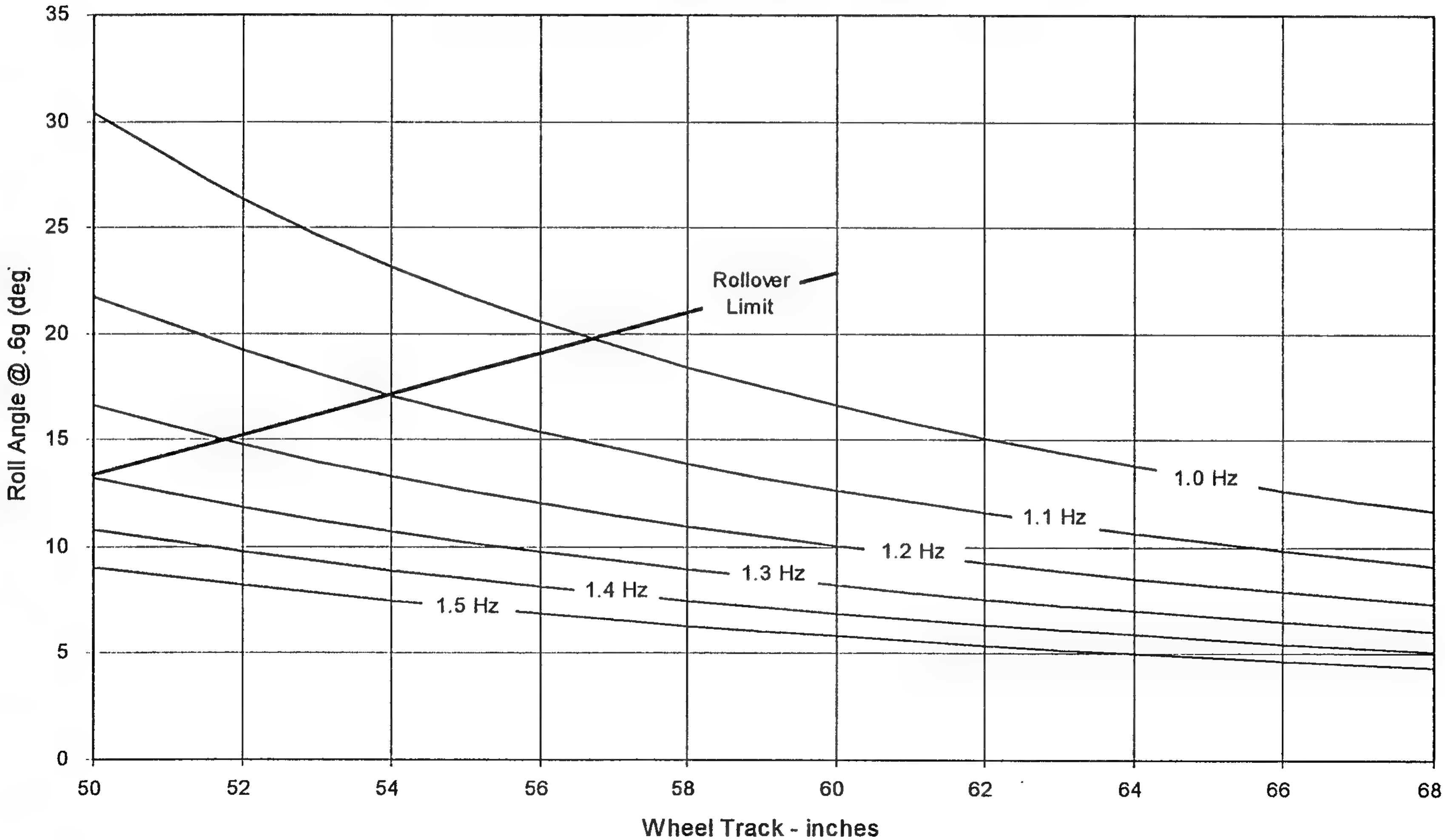
The roll stiffness should be neither too soft nor too stiff. If it is too soft, the vehicles tendency to rollover is increased. If it is too stiff, the low roll gives the driver a false sense of security in a hard turn because he losses his sense of impending rollover.

The draft specification calls for the body roll to be no more than 5 degrees at 0.6 G lateral acceleration. The Roll Angle chart shows the roll which might be expected for a notional RSTA-V having a cg height of 30 inches. It can be seen that the roll angle increases with reduced wheel track and reduced natural frequency. Since the wheel track of the GDLS RSTA-V concept is 66.1 inches, a bounce frequency in the neighborhood of 1.45 Hz is required to limit the roll to 5 degrees. This may provide too harsh a ride and it is anticipated that the bounce frequency will fall between 1.2 and 1.3 Hz. Without roll control the roll at 0.6 G would then be about 7.5 degrees. Air suspension allows for simple incorporation of roll control to reduce this to 5 degrees.

The RSTA-V Rollover chart shows the rollover G limit vs. wheel track and bounce frequency. Again the cg height is 30 inches. The stability increases with wheel track and roll stiffness. The curve labeled "Refrigerator" is for a rigid body of having no suspension. The "Tires Only" curve is for a notional RSTA-V with no other suspension than its tires. It corresponds to a bounce frequency about 2.9 Hz. The skid-out limit shown is for a coefficient of friction of 0.8 which might be expected on dry hard pavement. This limit is a function solely of the adhesion of the tires to the pavement and is independent of inertial geometry. The figure shows that the RSTA-V with a 66.1 inch wheel track will slide before tipping.

# RSTA-V Roll Angle

RSTA-V
Roll Angle vs. Wheel Track and Bounce Frequency



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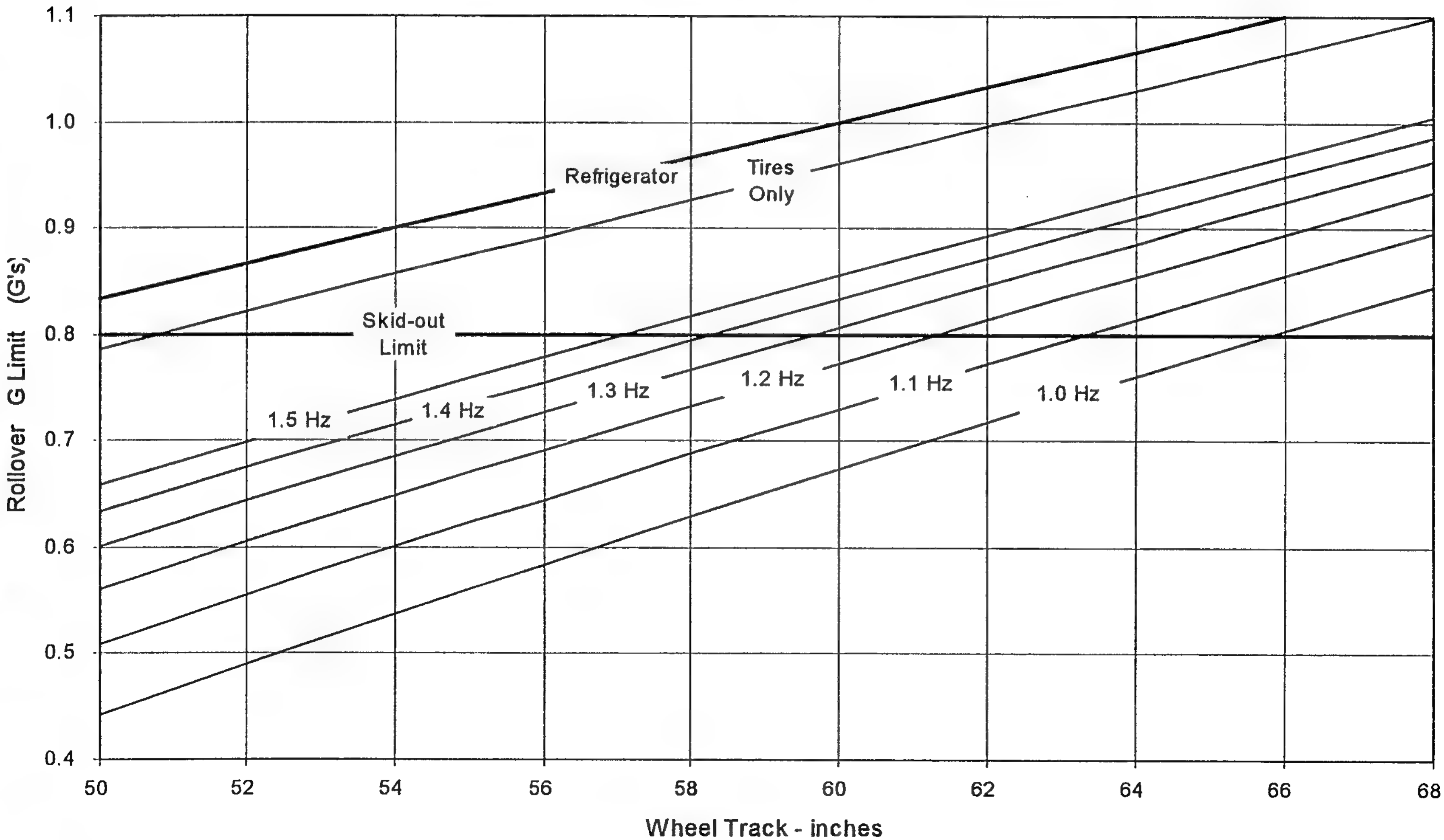
# RSTA-V Rollover

Rollover G Limit vs. Wheel Track and Bounce Frequency



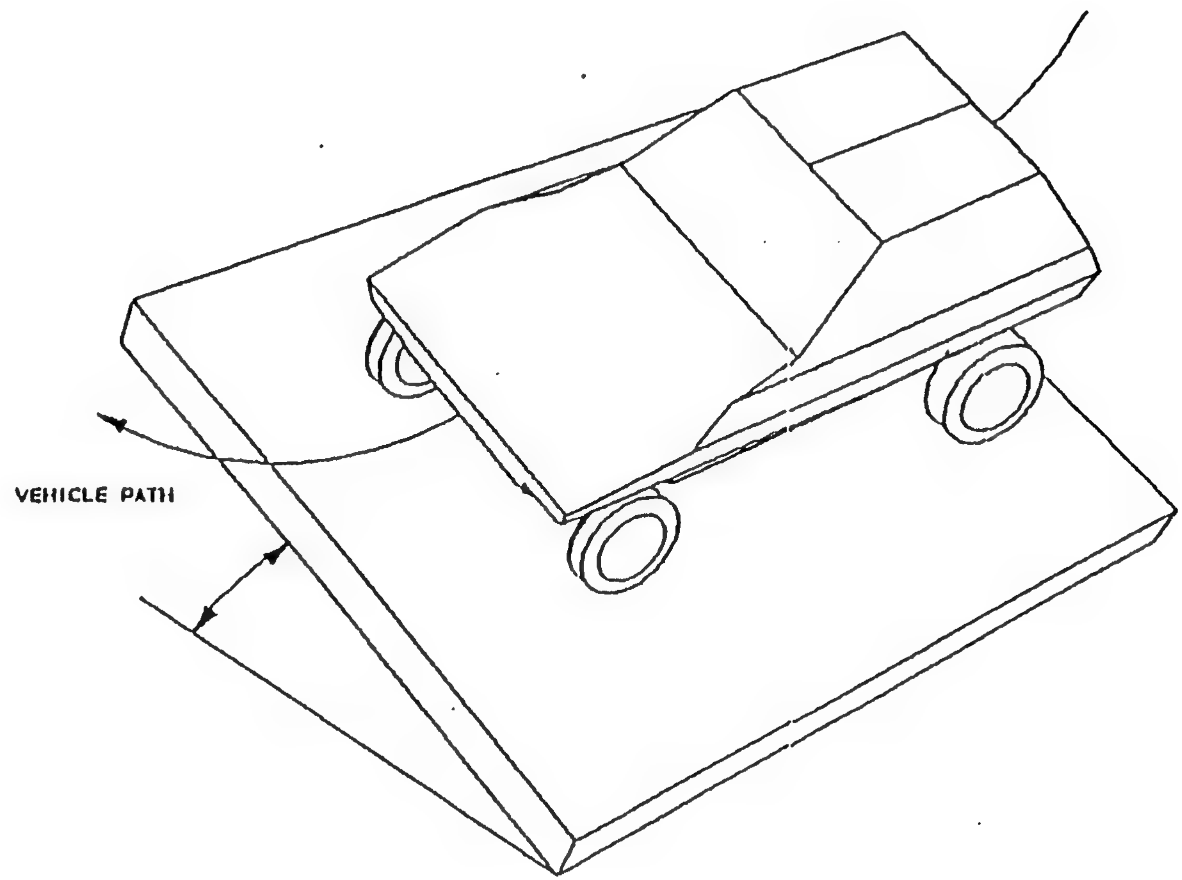
## Side Slope Stability

With regard to side slope operation the draft specification states that the vehicle should be able to traverse 40% slopes at speeds up to 15 mph (objective, 25 mph). (Ref. Paragraph 3.2.1.2.4.2 of Draft Spec.) Since the speed of a straight horizontal traverse would have little influence on the lateral stability of the vehicle, we presume that the requirement implies that the vehicle must negotiate some sort of slalom course which would impart lateral accelerations in excess of normal gravity directed down the slope. If this is the intent, either the placement of the slalom pylons or a minimum radius of curvature should be defined along with the target speed to establish the desired acceleration. Alternatively, the intended lateral G acceleration itself could be specified.

Depending upon the vehicle's stability in relation to its lateral traction coefficient the vehicle can lose control by tipping or sliding. Since traction coefficients higher than 0.85 are unlikely, all of our design approaches are stable enough to slide before tipping on a 40% side slope. Under these circumstances the lateral G's that can be sustained are a function of the slope angle and coefficient of friction between the vehicle and the ground. The Side Slope Spinout table gives the allowable lateral G limits on a 40% side slope for various friction coefficients. Also presented are radii of curvature and pylon spacing required to generate these G forces at the specified and objective vehicle speeds. Smaller radii and shorter spacing result in higher G's. The spacing assumes that the pylons are placed in a straight horizontal line across the slope to define a sine wave pattern having an overall amplitude equal to the vehicle width plus the pylon diameter. (Ref. ITOP 2-2-610(1), paragraph 4.2.) Note that the vehicle will slide before tipping for all coefficients of friction below 0.88.

The Side Slope Rollover Stability table and chart show the sensitivity of side slope stability to cg height. Note that, if the coefficients of friction are less than those indicated, the vehicle will slide before tipping.

# Side Slope Maneuver



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# RSTA-V
# Side Slope Spinout

Side Slope = 40%
Bounce Frequency = 1 Hz
Vehicle Track Width = 66.1 in
CG Height = 30.0 in
Vehicle Overall Width = 76.0 in

Pylon dia. = 14.0 in
Single Amplitude = 3.75 ft

Lateral Acceleration, G's = V^2/r/32.2
Speed = (mph)*22/15 ft/sec

Factor = PI()*22/15*SQRT(Amp/32.2
Factor = 1.57

| | Coefficient of Friction | Gs @ Spinout | Radius of Curvature (ft) | | Slalom Pylon Spacing (ft) | |
|---|---|---|---|---|---|---|
| | | | 15 mph | 25 mph | 15 mph | 25 mph |
| | 0.70 | 0.28 | 54 | 150 | 45 | 74 |
| | 0.75 | 0.33 | 46 | 128 | 41 | 69 |
| | 0.80 | 0.37 | 41 | 113 | 39 | 65 |
| | 0.85 | 0.42 | 36 | 100 | 36 | 61 |
| Rollover-> | 0.88 | 0.45 | 33 | 93 | 35 | 59 |

For coefficients of friction above 0.88 vehicle will rollover at values indicated for 0.88.

# RSTA-V
# Side Slope Rollover Stability

Side Slope = 40%
Bounce Frequency = 1.25 Hz
Vehicle Track Width = 66.1 in
CG Height = Variable in
Vehicle Overall Width = 76.0 in

Pylon dia. = 14.0 in
Single Amplitude = 3.75 ft

Lateral Acceleration, G's = V^2/r/32.2
Speed = (mph)*22/15 ft/sec

Factor = PI()*22/15*SQRT(Amp/32.2
Factor = 1.57

| CG Height (in) | Coefficient of Friction Required for Rollover | G's at Rollover | Radius of Curvature (ft) | | Slalom Pylon Spacing (ft) | |
|---|---|---|---|---|---|---|
| | | | 15 mph | 25 mph | 15 mph | 25 mph |
| 30 | 0.95 | 0.51 | 29 | 82 | 33 | 55 |
| 32 | 0.88 | 0.45 | 34 | 94 | 35 | 59 |
| 34 | 0.82 | 0.39 | 39 | 108 | 38 | 63 |
| 36 | 0.76 | 0.34 | 45 | 124 | 41 | 68 |
| 38 | 0.71 | 0.29 | 52 | 143 | 44 | 73 |
| 40 | 0.67 | 0.25 | 60 | 167 | 47 | 79 |

Vehicle will spin out before rolling over for coefficients of friction below those indicated.

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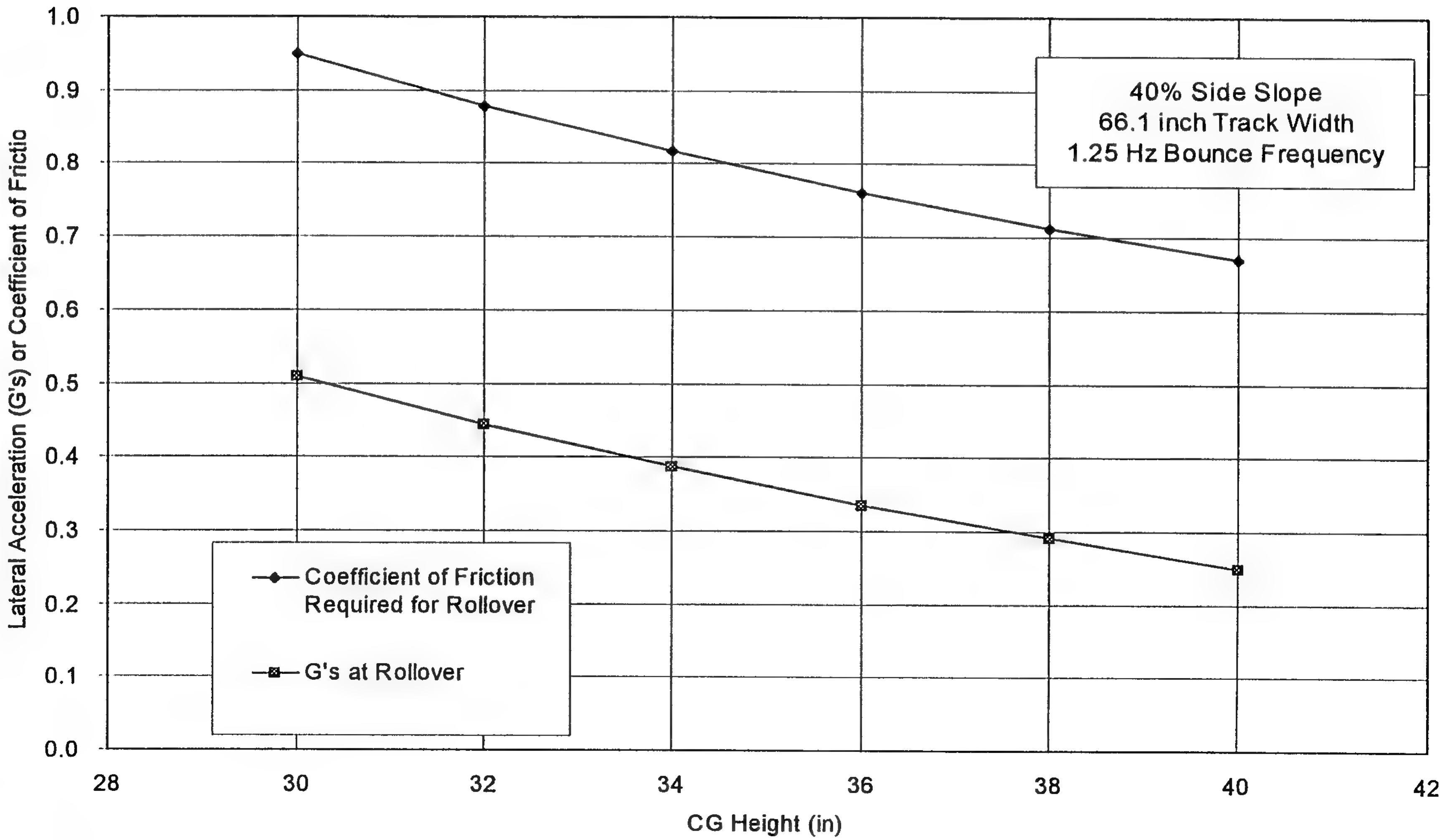
# RSTA-V
# Side Slope Rollover Stability



## Ride Quality

The draft specification includes requirements for ride quality over various rms courses and half-round obstacles. The determination of ride characteristics requires a point design and is beyond the scope of the program. However, the range of stiffness and high wheel travel afforded by GDLS' air suspension concept will provide ride quality similar or superior to that of the HMMWV. Thus, if the ride requirements desired are no more severe than those of the HMMWV, they should be easily attainable.

Concern has been expressed as to whether GDLS' approach, which incorporates in-hub electric motors, would have such high unsprung weight as to adversely affect its mobility performance. As a result of this concern, we have conducted a survey of the unsprung weight to GVW ratios of several different wheeled vehicles. The results of this survey are presented in the Comparison table and chart that follow. The data suggest that the unsprung weights for our RSTA-V are not out of line with respect to current practice, especially when compared to GDLS' Light Forces Vehicle, whose off-road performance was demonstrated during the IPR. Consequently, we anticipate no adverse problems resulting from unsprung mass.

Since unsprung mass is not commonly listed in vehicle specifications, it is difficult to obtain this information for any but our own vehicles. Consequently, we have resorted to data provided at various times by the government as sample input data for VEHDYNII. Presumably these data fairly represent the actual vehicles being modeled. The sources of the weight data are listed in the table.

# Unsprung Weight Comparison

| % Unsprung Weight/Total Vehicle Weight | | | | | |
|---|---|---|---|---|---|
| Vehicle | Front Axle | #2 Axle | #3 Axle | Total | Data Source |
| GDLS RSTA-V 4x4 | 21.1% | 14.0% | 0.0% | 16.9% | |
| GDLS LFV | 19.1% | 11.8% | 0.0% | 14.6% | |
| Teledyne FMTV 4x4 | 18.2% | 21.5% | 0.0% | 19.7% | |
| Surrogate FAV | 21.9% | 16.0% | 0.0% | 17.8% | PREVDYN2 Manual |
| M998 HMMWV (unladen?) | 16.1% | 20.4% | 0.0% | 18.0% | NRMM0596 distribution |
| M998 HMMWV | 14.6% | 11.2% | 0.0% | 12.7% | estimated laden |
| GDLS RSTA-V 6x6 | 18.9% | 25.2% | 25.2% | 22.7% | |
| Teledyne FMTV 6x6 | 19.6% | 19.9% | 19.9% | 19.8% | |
| M923 5 ton Truck | 24.2% | 25.1% | 25.8% | 25.0% | PREVDYN2 Manual |
| M35 2.5 ton Truck | 18.8% | 25.8% | 25.8% | 23.4% | NRMM0596 distribution |
| M939 5 ton Truck | 26.6% | 20.9% | 20.9% | 22.7% | NRMM0596 distribution |

"NRMM0596 distribution" refers to sample PREVDYN2 input data files furnished by Nancy Saxon in May, 1996, for use in the Marine Corps MTVR Program.

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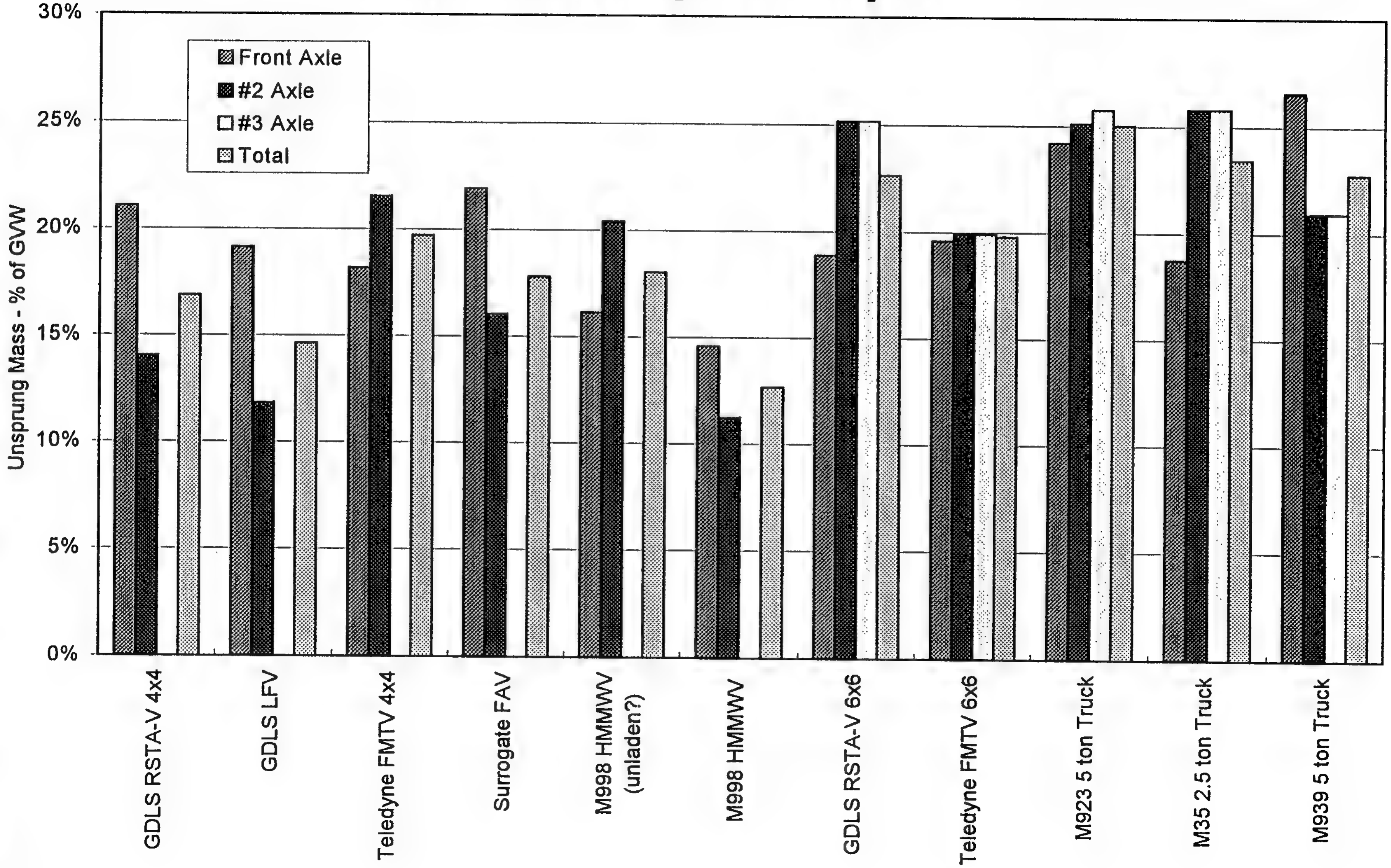
# Unsprung Weight Comparison

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**Off-Road Trafficability**

RSTA-V trafficability goals are presented the next table.

Vehicle Cone Index (VCI) is an indicator of sinkage in soft soils as well as a measure of traction limits. VCI's for the various concepts were calculated using the method of NRMMII version 2.5.8b. The results for various weight distributions and tire sizes and deflections are presented. Assuming equal weight distribution on all axles yields the most favorable VCI's. A weight distribution of 40% on the front axle and 60% on the rear axle(s) is more typical of real vehicles.

Note that all but the 4x4 with the small 7.50R20 tires can provide VCI's below the maximum allowable VCI of 22 required by the draft specification. However, only the 6x6 with large tires is better than the objective of 15. The 4x4 with 9.00R20 tires at 35% deflection has a VCI of 18.9, about the same as a 5 ton GVW HMMWV. In light of the penalties in cost, complexity and loss of payload volume presented by the 6x6, consideration should be given to what benefits in no-go reduction are gained by requiring the objective VCI of 15.

The tables and charts that follow show the sensitivity of VCI to tire deflection for the 4x4 and 6x6 with different size tires. The surface plot shows the influence of tire diameter and section width on the VCI of a notional RSTA-V 4x4. The next figure is a contour plot of the same data.

% No-Go's, Mobility Speeds, and Mission Rating speeds (MRS) are the results of NRMM analysis. As with ride quality, NRMM analyses can not be performed without a point design and are beyond the scope of the current program. However, if the objective % No-Go's and mobility speeds are comparable to those of the HMMWV, the should be achievable goals. The specification should give the formulae to be used to determine the MRS for the RSTA-V. The formulae should include NRMM scenarios and their weighting factors to be used in the calculations.

The Mission Profile states that the Average Mobility Speed should be equal to or greater than the average speed of the Ground Combat Element. The method for determining Average Mobility Speed is not defined nor is it given for the Ground Combat Element. These should be clarified in the specification.

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# RSTA-V Trafficability

| | Performance | Primary Issues | Draft Specification | |
|---|---|---|---|---|
| | | | Minimum | Objective |
| | Vehicle Cone Index (VCI) | Weight, CG Location, Tire Diameter, Width, and Deflection | 22 | 15 |
| | Ride Quality | Sprung and Unsprung Weights, Moment of Inertia, Suspension Stiffness and Damping, and CG and Crew Locations | Tabulated Absorbed Power and Acceleration Limits | |
| | Fording | Packaging and Sealing | 30 inch depth without kit<br>60 inch depth with kit | |
| | % No-Go | Geometry, Tractive Effort, Braking, Tire Diameter and Aggressiveness, All-wheel Drive, Suspension, CG Location | Tabulated Values for Various Geographical Areas | |
| | Mobility Speeds, e.g., V-80, V-90, etc. | Everything Discussed Previously | Tabulated Values for Various Geographical Areas | |
| | Mission Rating Speeds (MRS) | Same as Above | Same as Above - Need Formula | |
| | Average Mobility Speed | Same as Above | Equal to or greater than average speed of Ground Combat Element, i. e., M1A1, LAV, AAAV, and HMMWV. (Mission Profile) | |

# RSTA-V Vehicle Cone Index (VCI)

## 50-50 Weight Distribution

| Single Pass, Fine Grain (NRMMII, Ver 2.5.8b method) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | HMMWV | |
| Weight Distribution | | Tire Size | 7.50R20 | 9.00R20 | 37x12.5R16.5 | 37x12.5R16.5 | |
| | | GVW (lbs) | 8,000 | 8,000 | 8,000 | 8,500 | 10,000 |
| | | % Deflection | | | | | |
| 50-50 | 4x4 | 15 | 27.4 | 22.2 | 19.4 | 20.4 | 22.9 |
| | | 25 | 24.2 | 19.5 | 17.1 | 18.0 | 20.2 |
| | | 35 | 22.2 | 18.0 | 15.7 | 16.5 | 18.6 |
| 33-33-33 | 6x6 | 15 | 21.2 | 17.6 | | | |
| | | 25 | 18.6 | 15.5 | | | |
| | | 35 | 17.1 | 14.3 | | | |
| 33-67 | Half-Track | 15 | 19.7 | 16.5 | | | |
| | | 25 | 18.7 | 15.7 | | | |
| | | 35 | 18.2 | 15.3 | | | |
| 50-50 | Quad-Track | NA | 15.4 | | | | |
| | | Track Size | 43.5x10 | 46x11 | | | |
| NA | Full-Track | NA | 13.7 | | | | |
| | | Track Size | 105x10 | | | | |

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# RSTA-V Vehicle Cone Index (VCI)

## 40-60 Weight Distribution

| Single Pass, Fine Grain (NRMMII, Ver 2.5.8b method) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | RSTA-V | | | HMMWV | |
| Weight Distribution | | Tire Size | 7.50R20 | 9.00R20 | 37x12.5R16.5 | 37x12.5R16.5 | |
| | | GVW (lbs) | 8,000 | 8,000 | 8,000 | 8,500 | 10,000 |
| | | % Deflection | | | | | |
| 40-60 | 4x4 | 15 | 29.5 | 23.4 | 20.3 | 20.4 | 22.9 |
| | | 25 | 25.9 | 20.5 | 17.8 | 18.0 | 20.2 |
| | | 35 | 23.7 | 18.9 | 16.4 | 16.5 | 18.6 |
| 40-30-30 | 6x6 | 15 | 21.7 | 18.0 | | | |
| | | 25 | 19.1 | 15.8 | | | |
| | | 35 | 17.5 | 14.5 | | | |
| 40-60 | Half-Track | 15 | 20.7 | 17.1 | | | |
| | | 25 | 19.0 | 15.9 | | | |
| | | 35 | 18.2 | 15.2 | | | |
| | Quad-Track | NA | 16.0 | | | | |
| | | Track Size | 43.5x10 | 46x11 | | | |
| NA | Full-Track | NA | 13.7 | | | | |
| | | Track Size | 105x10 | | | | |

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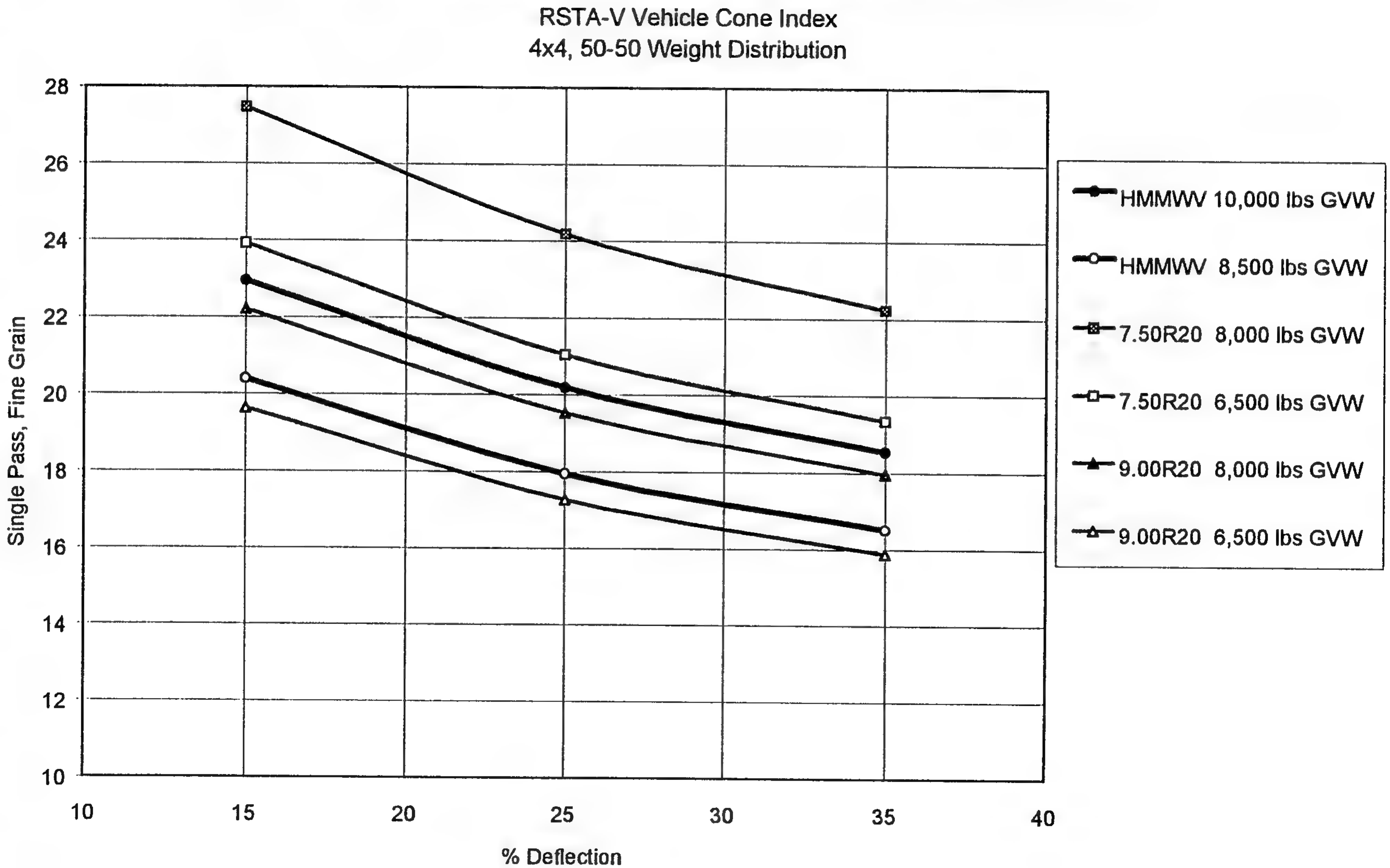
# RSTA-V Vehicle Cone Index (VCI) 4x4



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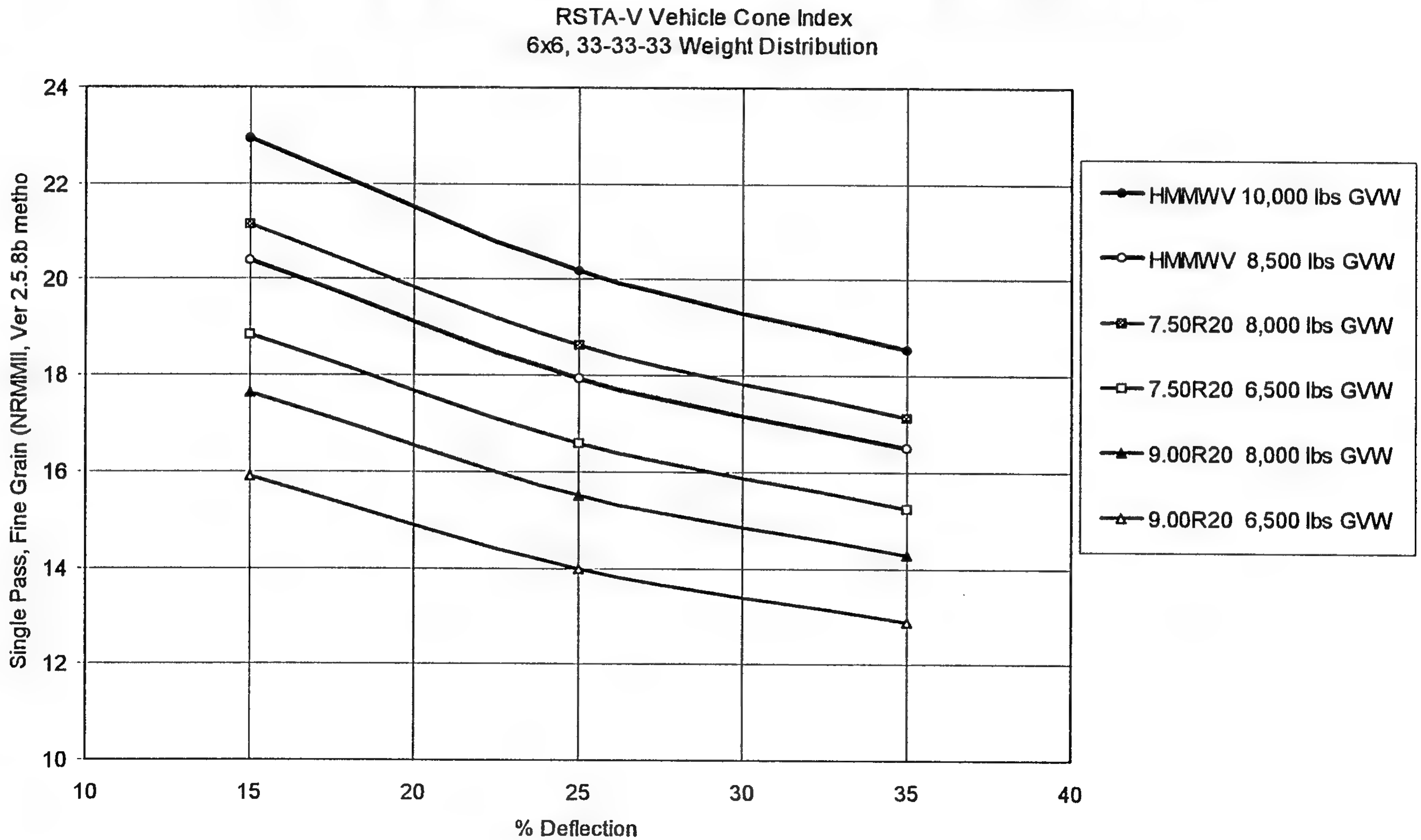
# RSTA-V Vehicle Cone Index (VCI) 6x6

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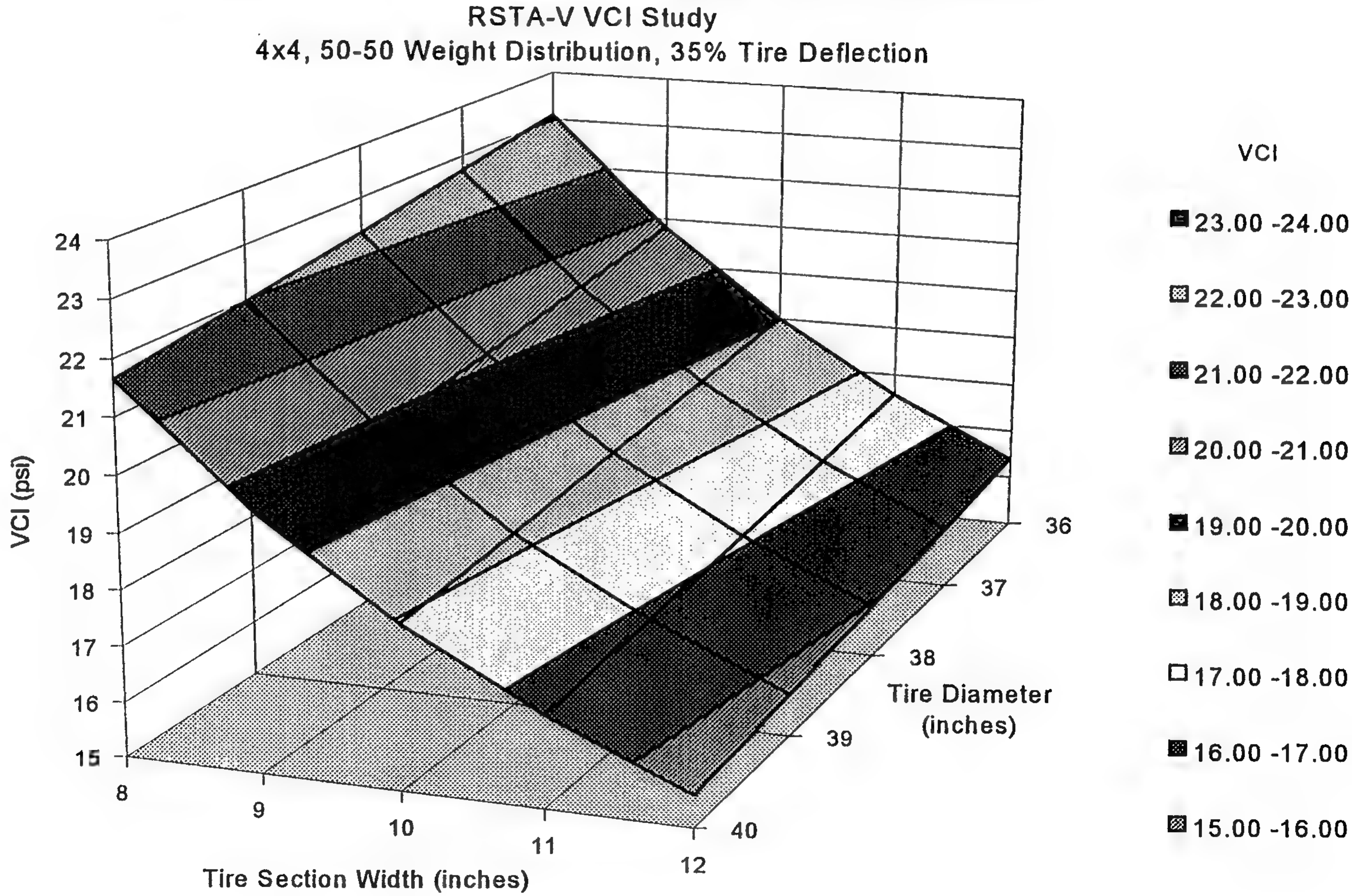
# RSTA-V Vehicle Cone Index (VCI)
# VCI vs. Tire Width and Diameter



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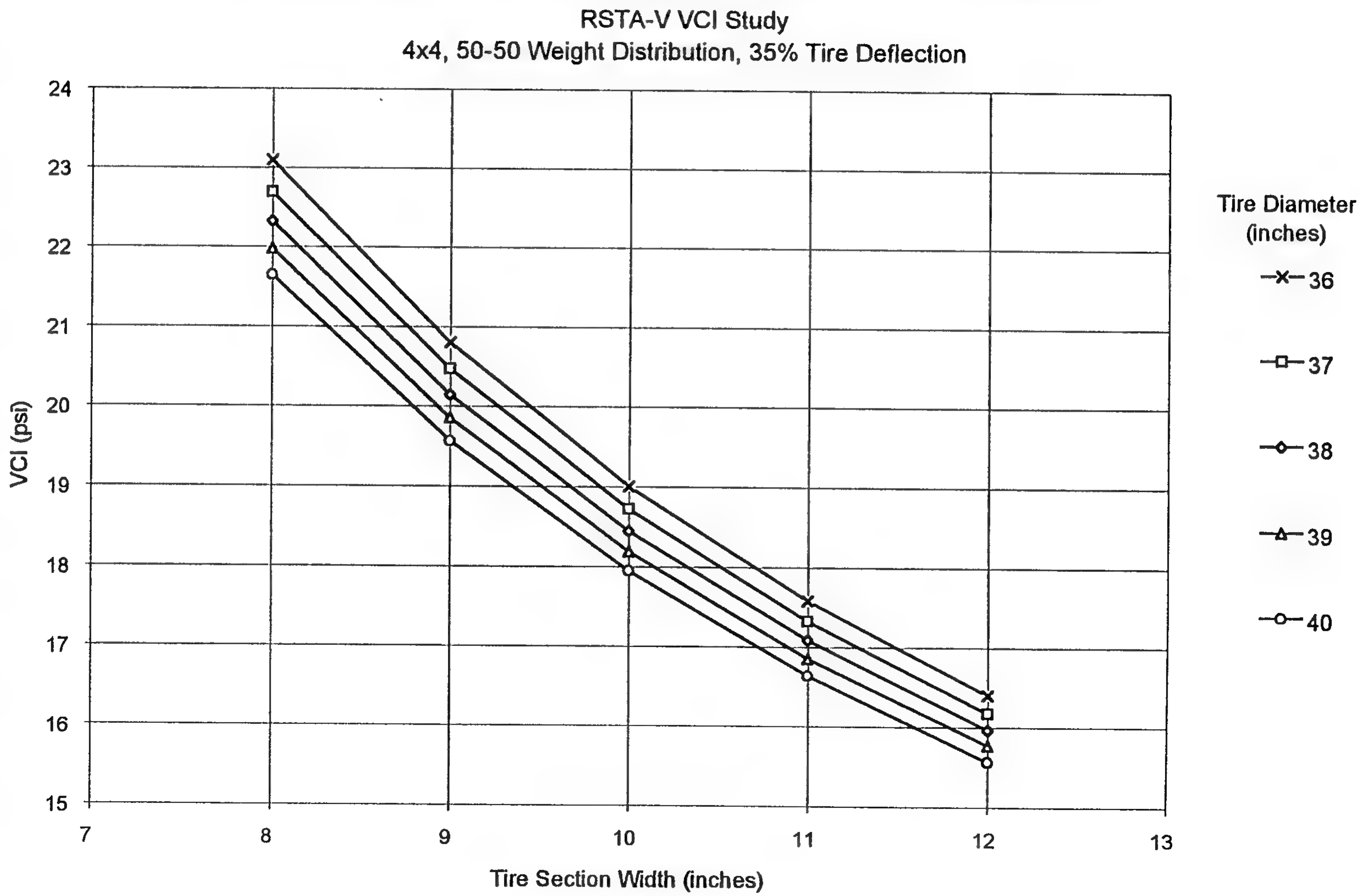
# RSTA-V Vehicle Cone Index (VCI)
# VCI vs. Tire width and Diameter



## Obstacle Negotiation

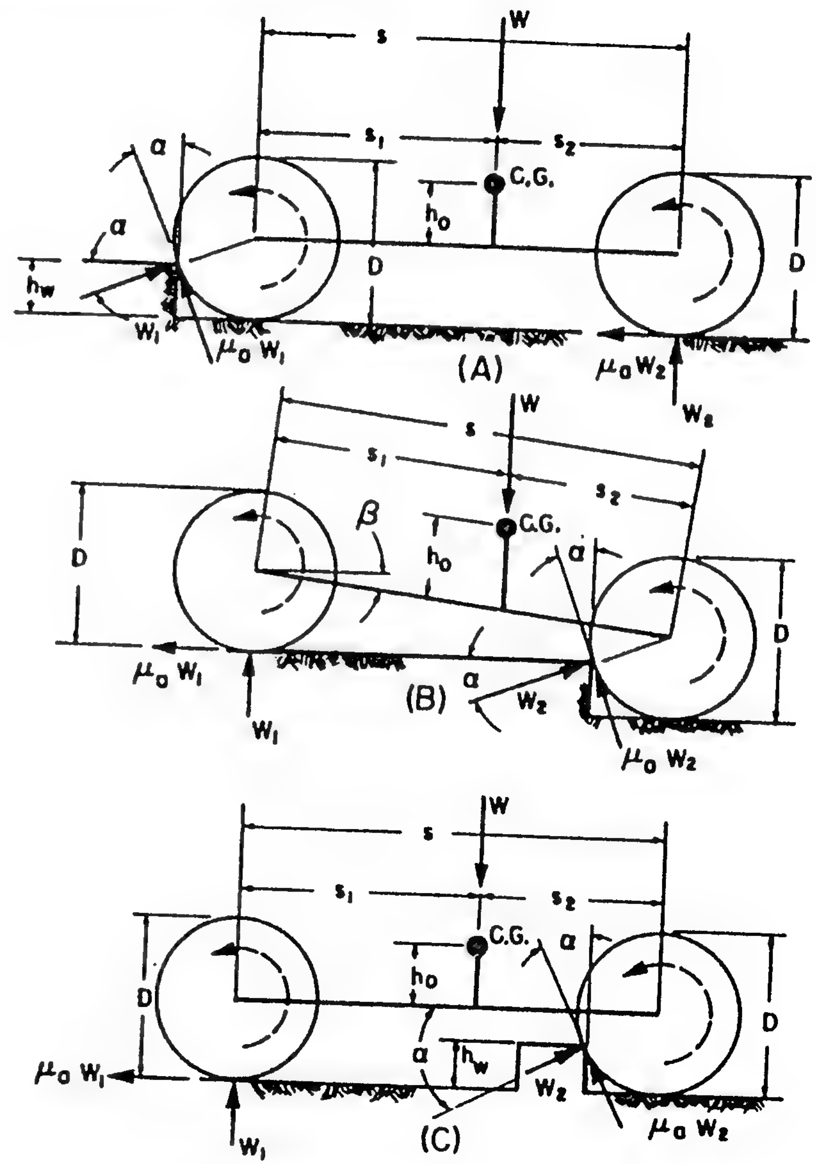
The draft specification requires that the RSTA-V be able to climb a vertical step 15 inches high. The objective height is 18 inches. The following figure illustrates the factors affecting the climbing ability of a 4x4. It is rare that a wheeled vehicle is capable of negotiating a step as high as half its wheel diameter. Generally, the friction forces are insufficient to permit it. If the vehicle does get its first axle over the step, say by catching a lug on the corner, it may lack the torque required to lift its rear end. The higher the step height the larger the tire diameter and the higher the tractive effort must be. Each of these factors increases the required motor torque which, in turn, drives motor size, weight, and cost. Serious consideration must be given to the selection of the minimum step height. How important will it be to mission performance? How high and how frequently are these steps expected to be encountered? (Ref. Paragraph 3.2.1.2.4.3 of Draft Specification.)

## Cooling

The draft specification does not address cooling. Cooling test requirements for the HMMWV and FMTV specified that the vehicles should be capable of generating 0.7 tractive effort continuously on a 120 degree F day without overheating. RSTA-V requirements should be the same

# Vertical Step Climbing

Vehicle with Two Axle Drive Encountering Vertical Obstacles (A) Front wheels encountering vertical obstacle (B) Rear wheels encountering plateau-type wall (C) Rear wheels encountering a vertical bump type wall



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## Summary

The final chart of this section summarizes some of the attributes that comprise a high mobility vehicle.

# HOW TO SQUEEZE MOST TRACTION OUT OF WHEELED 4X4
## *(also applicable to 6x6 and 8x8)*

- AT LEAST 60° APPROACH/DEPARTURE ANGLES
- HIGH WHEEL TRAVEL AND “SOFT” SUSPENSION RATES FOR MAXIMUM TIRE CONTACT/TRACTION ON UNEVEN, SLIPPERY TERRAIN
- MAXIMUM PRACTICAL BELLY CLEARANCE(maybe the only benefit of an 18.5° ramp requirement)
- MAXIMUM PRACTICAL TIRE SIZE
- CENTRAL TIRE INFLATION
- ABSOLUTE TRACTION CONTROL-- ALL WHEELS (E-drive strength)
- TIRE TREADS THAT ARE GOOD ON HIGHWAYS AT HIGH PRESSURE AND BECOME INCREASINGLY AGGRESSIVE AS TIRE DEFLECTION INCREASES
- MODERN EQUIVALENTS TO CHAINS THAT WRAP AROUND TIRES AND HAVE VERY AGGRESSIVE TREADS (must work at low tire pressure)
- TRACK DRIVE “KITS” WITH GOOD APPROACH ANGLES (vehicle design must anticipate space claim)

## Mechanical Subsystems

The following section addresses the primary mechanical subsystems which require selection or design to achieve a vehicle concept compatible with the intent set forth.

**Engine:** The initial subsystem addressed is the engine or power plant as to which type is more ideal for the intended application. Additionally this selection review considers factors such as cost, mature or developing technology, reliability, etc.

**Suspension:** Another major subsystem addressed is the suspension system, where the uniqueness of the need requires a new suspension design, employing proven principles.

**Auxiliary Subsystems:** Auxiliary subsystems discusses those systems needed to support the major systems. Such subsystems involve pneumatics to support tires and suspensions, and cooling to support the engine and electronics to mention a couple.

**Hull:** The last major subsystem addressed is the hull structure and its weight implications.

## Engine Subsystem Concept Description

The engine subsystem refers to the hardware required to support the prime power plant and delivery of the power to move the vehicle and operate its accessories. Items or components that are considered part of engine subsystem are the following:

- engine
- fuel system
- starting system
- power take off (electrical)
- cooling systems
- induction and exhaust

The hybrid electric vehicle will not provide a mechanical power takeoff. The power train, (engine/ generator/ motor) is intended to provide only electrical power for driving the vehicle in addition to operating accessories and equipment.

The air induction and exhaust systems must be shielded for noise and thermal signature. These would be of a specific design compatible with the vehicle and engine selected and are not addressed in this report.

## Engine Performance Goals

Engine performance goals were established to achieve the key operating considerations listed on the following page. Additional factors such as transporting the vehicle in the V-22 aircraft were also considered. Other selection issues are engine availability and price. A summary of key goals is listed here.

-150-200 horsepower
-engine speed for generator compatibility
-power density >200 watt/lb.
-minimum space claim of 65"l x 30"w x 30"h
-fully developed
-economical price
-multi-fuel
-fuel efficient

The goals for the RSTV engine resulted from operating mode guidelines supplied by the customer and those needs detailed by supplementary equipment and engine accessories. These are defined by the following chart and graph. In cases where engine horsepower is not sufficient, primarily vehicle acceleration modes, capacitors and batteries are used to supplement the power plant.

# RSTA-V KEY OPERATION CONSIDERATIONS

| | CONDITIONS | SPEED (MPH) | GRADE 0/0 | HORSEPOWER REQUIREMENTS ENGINE POWER | SUPPL: POWER | COOLING POWER | STEER POWER | AIR CONT. POWER | TOTAL MAX HP | HP 85% |
|---|---|---|---|---|---|---|---|---|---|---|
| A. | CRUISING SPEED-MINIMUM | 60 | 0 | 49 | 33 | 45 | 2.5 | 2.5 | 132 | 156 |
| B. | CRUISING SPEED - OBJECTIVE | 75 | 0 | 81 | 33 | | | | 164 | 194 |
| C. | SPEED ON GRADE-MINIMUM | 40 | 5 | 64 | 33 | | | | 147 | 173 |
| D. | SPEED ON GRADE-OBJECTIVE | 60 | 5 | 112 | 33 | | | | 195 | 230 |
| E. | ~~MINIMUM GRADABILITY~~ | ~~10~~ | ~~60~~ | ~~113~~ | ~~13~~ | | | | ~~176~~ | ~~208~~ |
| F. | DASH SPEED - MINIMUM | 70 | 0 | 69 | 13 | | | | 132 | 156 |
| G. | DASH SPEED - OBJECTIVE | 75 | 0 | 81 | 13 | | | | 144 | 170 |
| | ACCELERATION | | | | | | | | | |
| H. | 0.30 MPH MINIMUM | 30 | 0 | 91 | 13 | | | | 154 | 182 |
| I. | 0-30 MPH OBJECTIVE | 30 | 0 | 139 | 13 | | | | 202 | 238 |
| J. | 0-60 MPH MINIMUM | 60 | 0 | 158 | 13 | | | | 221 | 261 |
| K. | 0-60 MPH OBJECTIVE | 60 | 0 | 230 | 13 | | | | 293 | 345 |
| L. | CROSS COUNTRY | 15 | 0 | 48 | 33 | | | | 131 | 155 |
| M. | CROSS COUNTRY - DASH | 50 | 0 | 124 | 13 | | | | 187 | 220 |
| N. | SPEED ON GRADE | 50 | 10 | 135 | 13 | | | | 198 | 233 |

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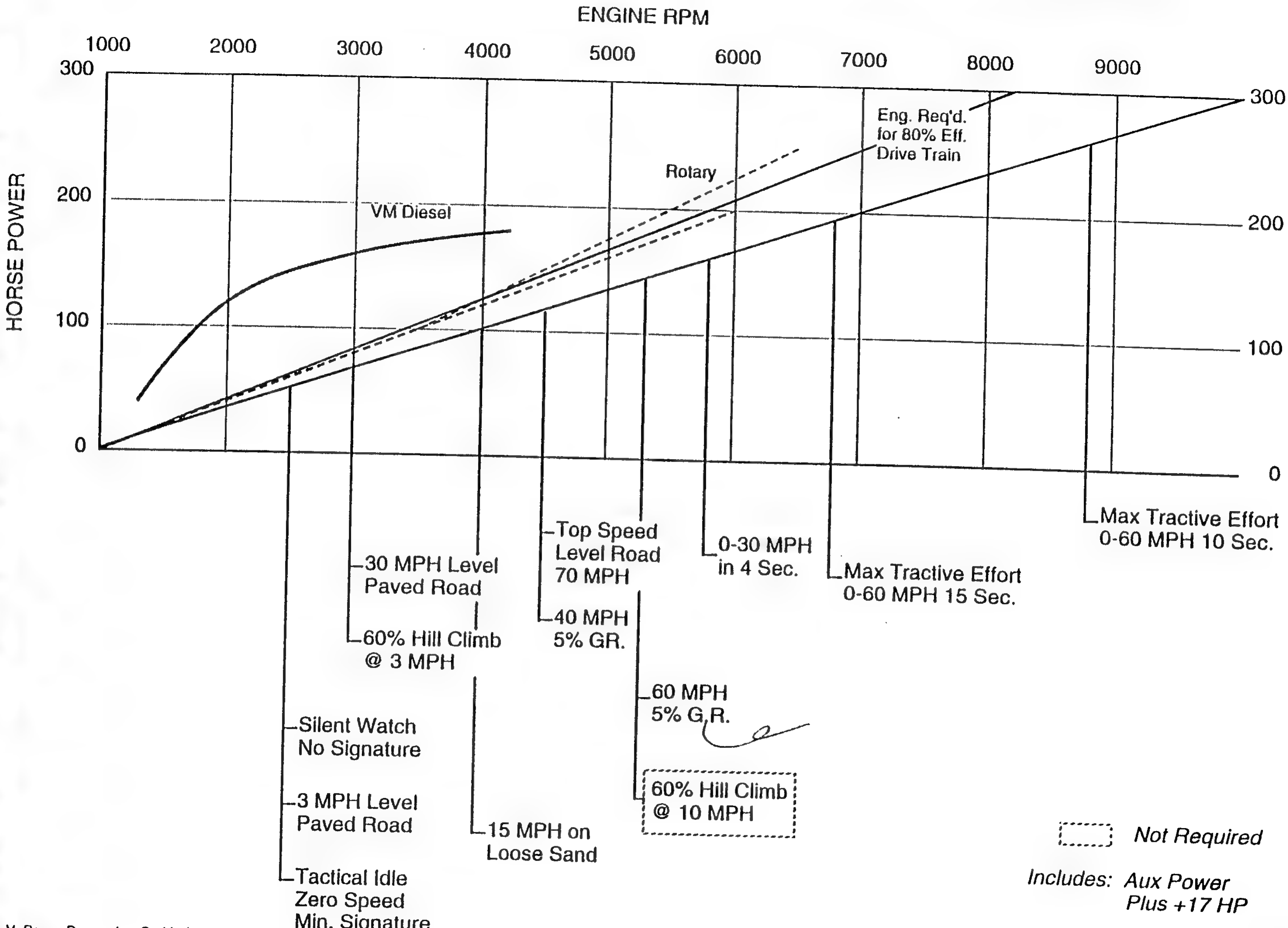
# RSTA-V POWER DEMAND VS. OPERATIONAL MODE



## Engine Types Considered

There were several types of power plant initially considered for the RSTV. These consisted of turbine, rotary, and diesel engines. The turbine was not considered a viable option because of its high cost, in the range of $100,000. To $200,000. The remaining two considerations were evaluated for what each could offer in terms of power density, primarily because of the need for good power in a small package. This being dictated by the limited space for transport offered by the V-22 aircraft.

The study reviewed one rotary and numerous diesel engines from General Motors, Detroit Diesel, Peugeot Citroen, and others. The most viable candidates surfaced after rejecting others on the basis of being to large or heavy, and having insufficient horsepower. The remaining candidates and their features are shown on the following table. This chart is followed by the pros and cons for each individual selection.

## Engine Selection

The engine selection based on the following information presented is a diesel. The factors which lead to this conclusion is that they are already part of the military system which is beneficial in many respects. Lower product cost and implementation costs also prove beneficial to the cost constraints being implemented in the military today.

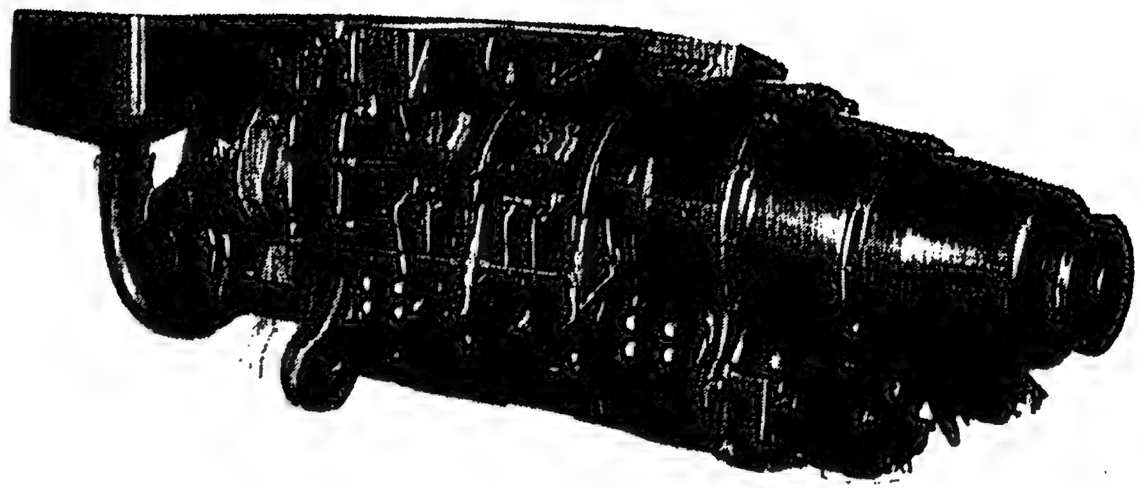
The rotary is seen as having future potential when production volumes occur and the costs are reduced as a result. The power density and multi-fuel aspects present advantages over today's diesel.

The several diesels presented all are fairly close in parameters so the most logical choice of these is the 190 hp general motors diesel used in the HMMWV.

# RSTA-V Potential Power Plant Selections

| Manufacturer | Rotary Engine | G.M. Diesel | V.M. Motori Diesel | V.M. Motori Diesel |
|---|---|---|---|---|
| Model | 70 Series 2013R | 6.5L-V8 | Turbo-tronic 638 | Diatonic D642 |
| Peak HP | 250 | 190 | 177 | 180 |
| Peak RPM | 6500 | 3400 | 4200 | 3200 |
| Peak Torque (ft. lb.) | 200 | 385 | 324 | 324 |
| Weight (lbs.) | 325 | 768 | 639 | 638 |
| Length (ins.) | 37.2 | 30.0 | 35.4 | 37.5 |
| Width (ins.) | 16.5 | 26.2 | 24.2 | 22.5 |
| Height (ins.) | 17.7 | 30.0 | 27.2 | 28.1 |
| Engine Space Claim (cu. in.) | 10,864 | 23,580 | 23,301 | 23,709 |
| Watt/lb. | 574 | 184 | 207 | 210 |
| Fuel Consumption lb/bhp.hr | 0.40 | 0.40 | 0.394 | 0.343 |
| Proto. Price | $75,000 | $6,000 | $6,700 | TBD |
| Prod. Price | $16,000 | $6,000 | $5,900 | TBD |

# RPI 2013R ROTOR ENGINE



## PRO

Best Power Density
50% Less Weight Engine
Highest Peak Horsepower
Highest RPM Engine
Multi-fuel Engine
50% Less Space Claim
U.S.-Based Company
Direct Fuel Injection

## CON

No Military Field Experience
Highest Price
Fuel Consumption Second Best
Pre-Manufacturing Phase

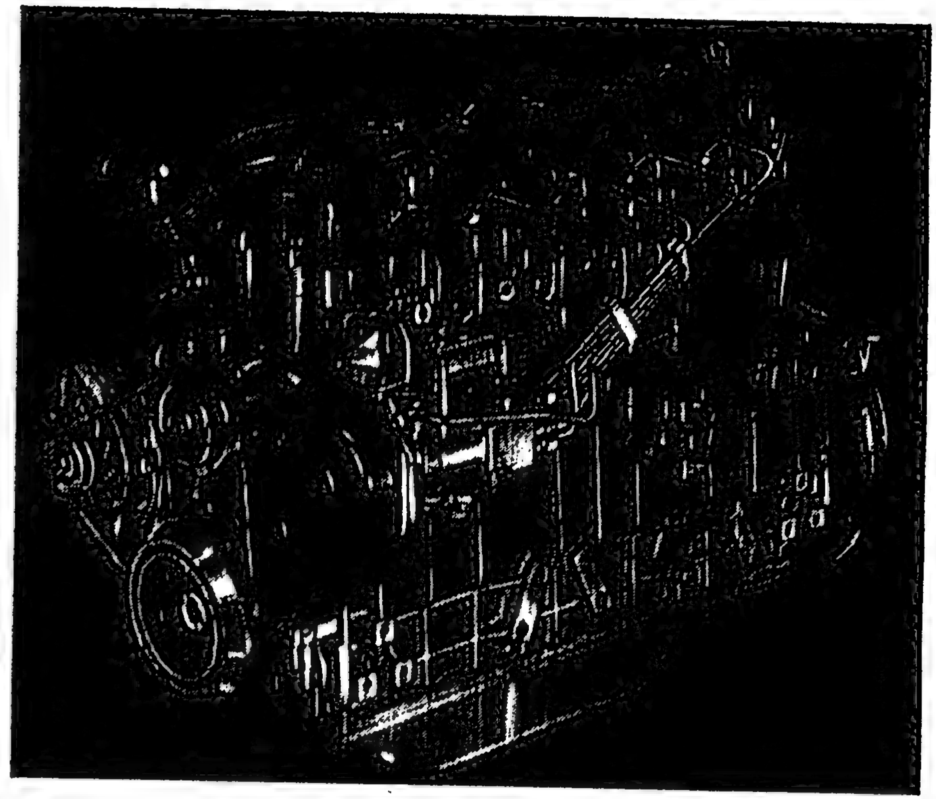
# VM MOTORI 638 DIESEL

**PRO**

Highest Peak RPM for Diesel
Lowest Weight for Diesel
Power Density Very Good
Price Equivalent to GM
Smallest Space Claim for Diesel
U.S. Owned Company

**CON**

Peak HP 13 Less than GM
Indirect Fuel Injection
Foreign Manufactured



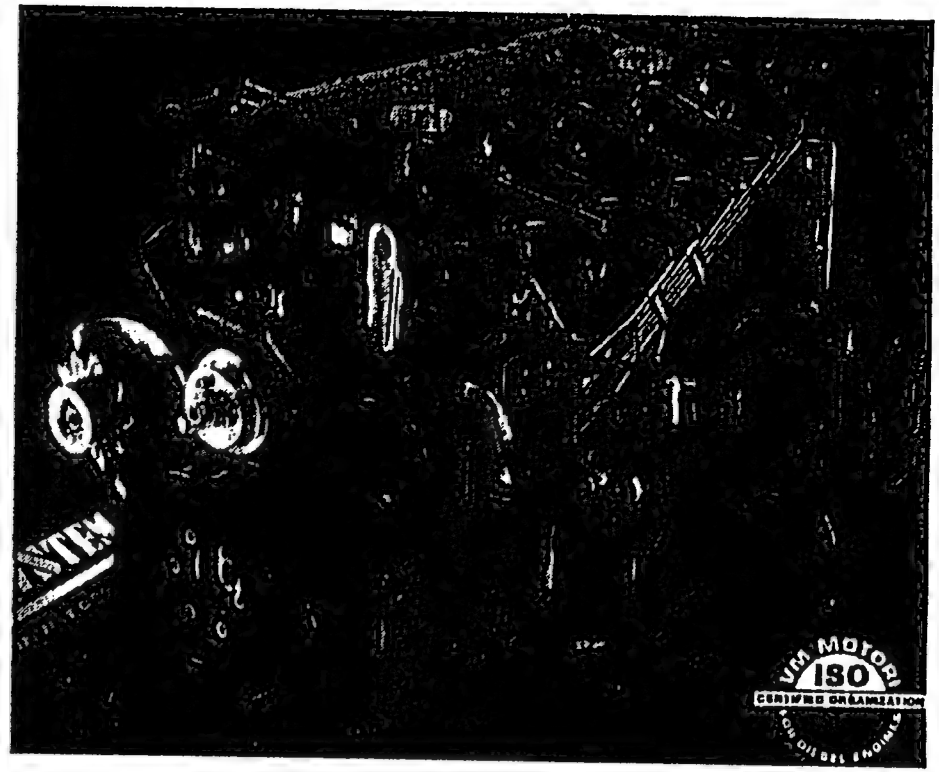
# VM MOTORI D642 DIESEL

**PRO**

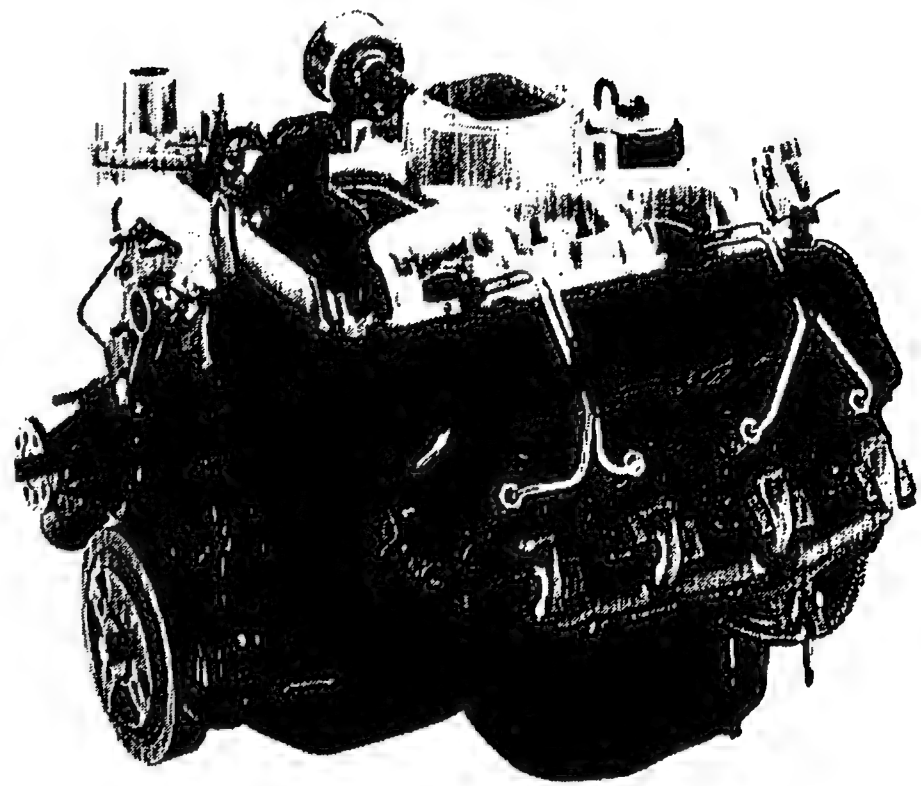
Highest Diesel Power Density
Direct Fuel Injection
Lowest Diesel Fuel Consumption
Lowest Weight for Diesel
U.S. Owned Company

**CON**

Peak HP 10 Less than GM
Foreign Manufactured
New Engine in 1997
No Military Field Exp.



# GENERAL MOTOR 6.5L DIESEL



**PRO**

High Peak Diesel HP
Military Field Experience
U.S. Owned Company
U.S. Manufactured
Priced Competitively

**CON**

Heaviest of Diesels
Fuel Consumption Second Best
Indirect Fuel Injection
Lowest Diesel Power Density

## Vehicle Cooling System

The vehicle cooling system must cool both the engine system, electric drive, and control system. The initial concept to divide the system in two parts resulted from using oil as a coolant in the electric drive motors and control system. The engine cooling loop uses a water/ethylene glycol mix to cool the engine, engine oil, and charge air if required. A coolant-to-air radiator is employed to dissipate the heat. An engine mounted fan provides air flow through the radiator. The fan is declutched when the required cooling is achieved. The cooling capacity is sized at 7000 Btu/min. The electrical cooling system uses an oil coolant and is used to cool the controls, wheel motors, and generator. This system has its own radiator and cooling fan. The cooling capacity for the system is sized at 1282 Btu/min.

An optional single fan concept can also be considered. This idea employs an electric motor to drive the fan when the engine is shut off and the fan declutched from the engine drive. In this mode the oil coolant would be circulated by an electric pump in the system.

A block diagram of the cooling system is shown on the following page.

# COOLING SYSTEMS

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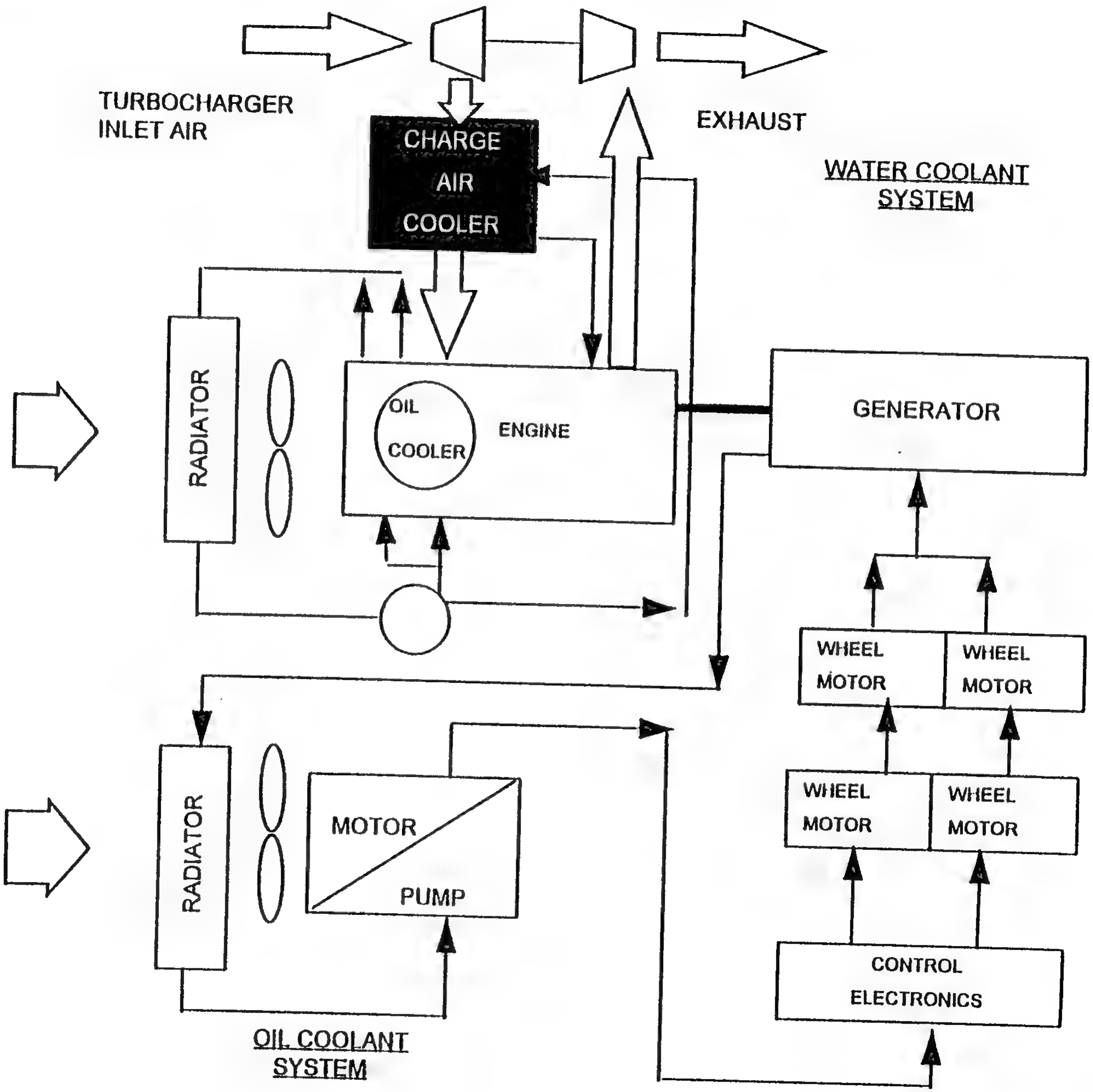




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**Suspension Subsystem Description**

The suspension subsystem includes steering and supports the vehicle while providing vehicle tractive effort, steering, height control, braking, and ride comfort by stabilizing the vehicle while traveling over the ground. The subsystem consists of the following:

-wheels
-tires and/or tracks
-steering gear and linkage
-suspension springs
-shock absorbers
-"a" arm and knuckle

Suspension Design Goals

The design goal is to provide a suspension that would allow a vehicle to fit inside a V-22 aircraft and still provide a track width that approaches that of the a HMMWV. To meet this criteria, the suspension would have to fold or by some other means, move into vehicle body for V-22 transport. Once out of the aircraft, the suspension would than extend and utilize the expanded track width for stability. The RSTV concept design incorporates this feature in addition to working toward the other design goals listed here:

-tires to achieve the best VCI
-maximize vehicle mobility
-maximize suspension travel for off road capability
-minimize unsprung weight
-achieve off/on road ride quality
-adjustable ride heights
-allow for 25' turning radius

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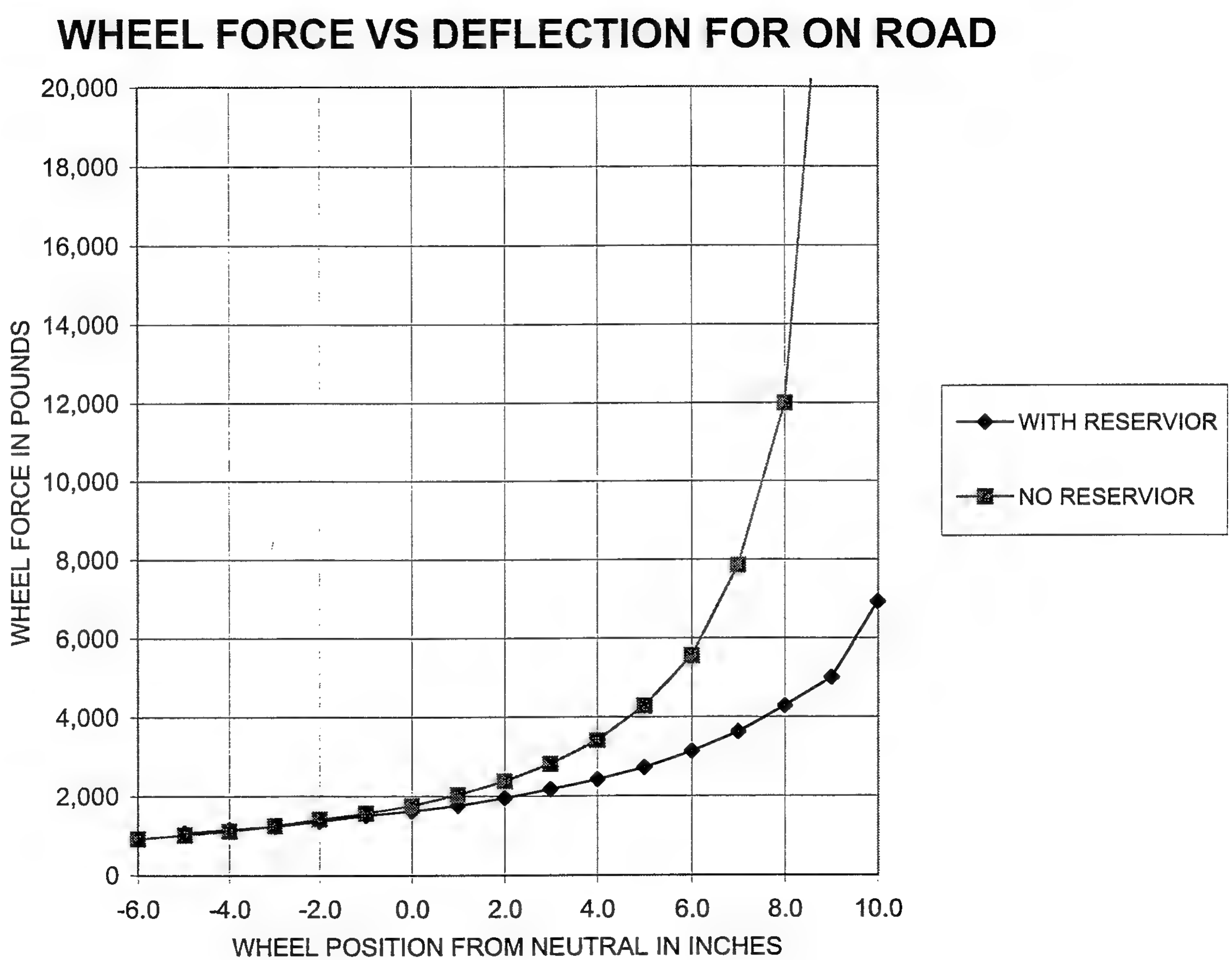

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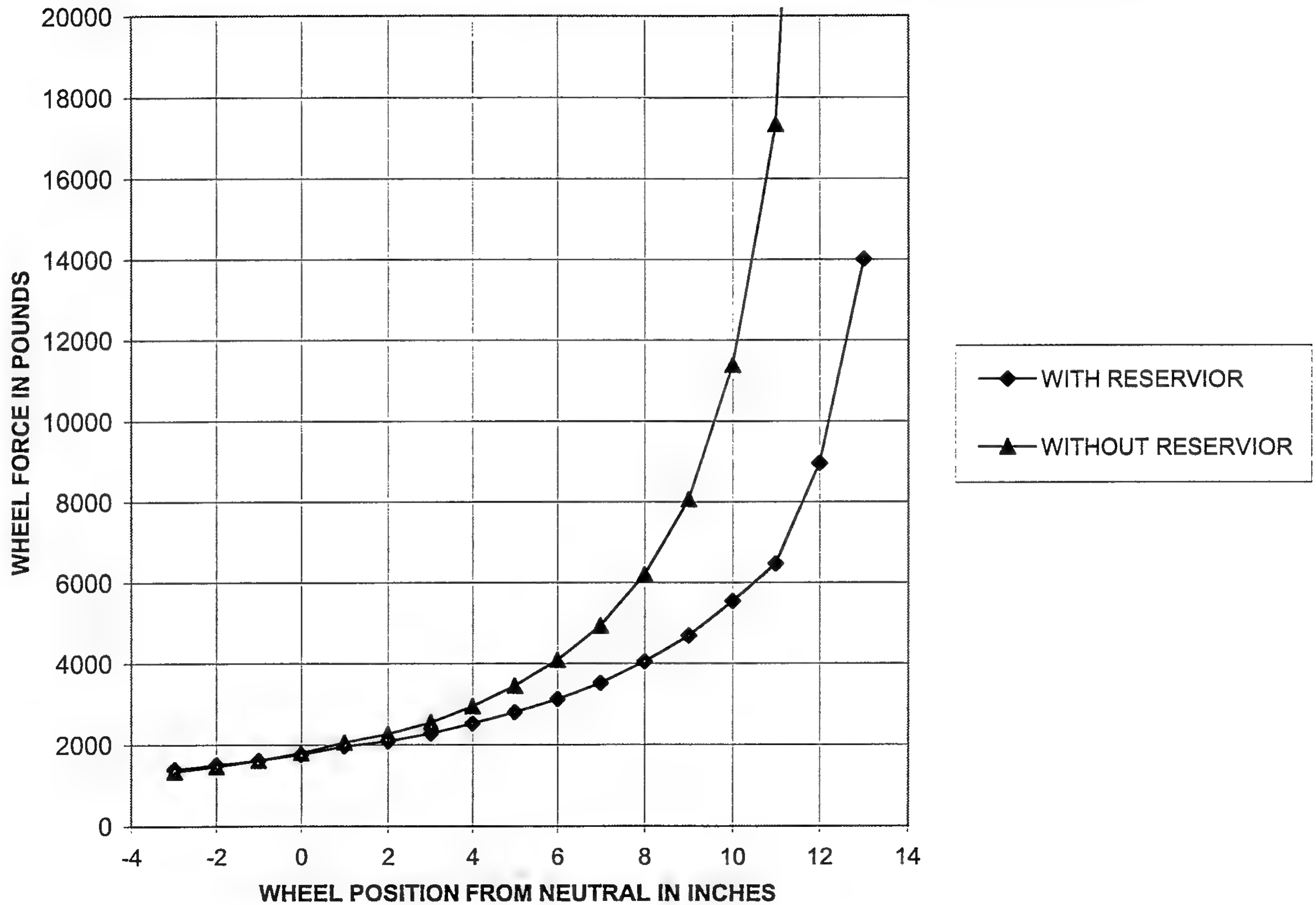
# WHEEL FORCE VS DEFLECTION FOR OFF ROAD

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**Tires and Track**

The various vehicle concepts were fitted with the best tire which was compatible with that vehicle's envelope. Tandem drives were fitted with band tracks as an optional approach. Mattracks were also explored as a possible concept offering some tractive benefit. Mattracks, however presented excessive space utilization problems, requiring design modification to the product. The goal was to use the lightest assembly of tire and rim, including bead locks and run flats, and remain as narrow as possible. Also while doing this achieve VCI numbers which are less than the 22 required. The chart on the following page summaries the in wheel motor vehicle concepts and the wheel end characteristics of each. The tires are military with sand or off-road tread produced by Michelin.

Weight becomes a major issue for concepts with more than four wheels.

# IN WHEEL MOTOR CONCEPT

| VEHICLE CONFIGURATION | 4 X 4 | 6 x 6 | 6X6 SEMI-ART. | HALF TRACK | 8 X 8 |
|---|---|---|---|---|---|
| DRIVING WHEELS | ALL | ALL | ALL | ALL | ALL |
| TIRE SIZE | 900R20 | 750R20 | 750R20 | 750R20 | 750R20 |
| TIRE WIDTH (INS.) | 9.9 | 8.2 | 8.2 | 8.2 | 8.2 |
| 8000 GROSS VCI | 18.9 | 17.5 | 17.5 | 18.2 | - |
| 6500 GROSS VCI | 16.6 | 15.6 | 15.6 | - | - |
| SUSP./WHEEL END WT. (Lbs.) | 1936 | 2411 | 2536 | 2771 | 3015 |
| TIRE WEIGHT (Lbs.) | 100 (400) | 62 (372) | 62(372) | 62 (372) | 62 (494) |
| RIM WIDTH (Ins.) | 7 " | 6 " | 6" | 6 " | 6" |



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**Auxiliary Subsystem Description**

The auxiliary subsystems are those devices needed to supplement the main vehicle system and perform numerous tasks. These subsystems include the following:
-electrical system
-environmental controls
-air system system

The air system is of prime importance to the functioning of the RSTV since it has a number of support functions. Two major functions supported by air are the air suspension and central tire inflation systems. The air system provides air to the suspension air springs and operates the operational level of the vehicle going between on road and off road. With valuing the air is used to support height control and roll control. The second major use of air is to operate the central tire inflation system via sensors and controls and a manual selection switch for the operator.

The use of air to operate auxiliary devices is another function performed by the air system. Some of these potential devices are:

-operate air tools
-raise a sensor mast
-in-place vehicle jacks
-winch assist air wedge

The block diagram on the following page and the circuit diagrams in the appendix detail typical air circuits.

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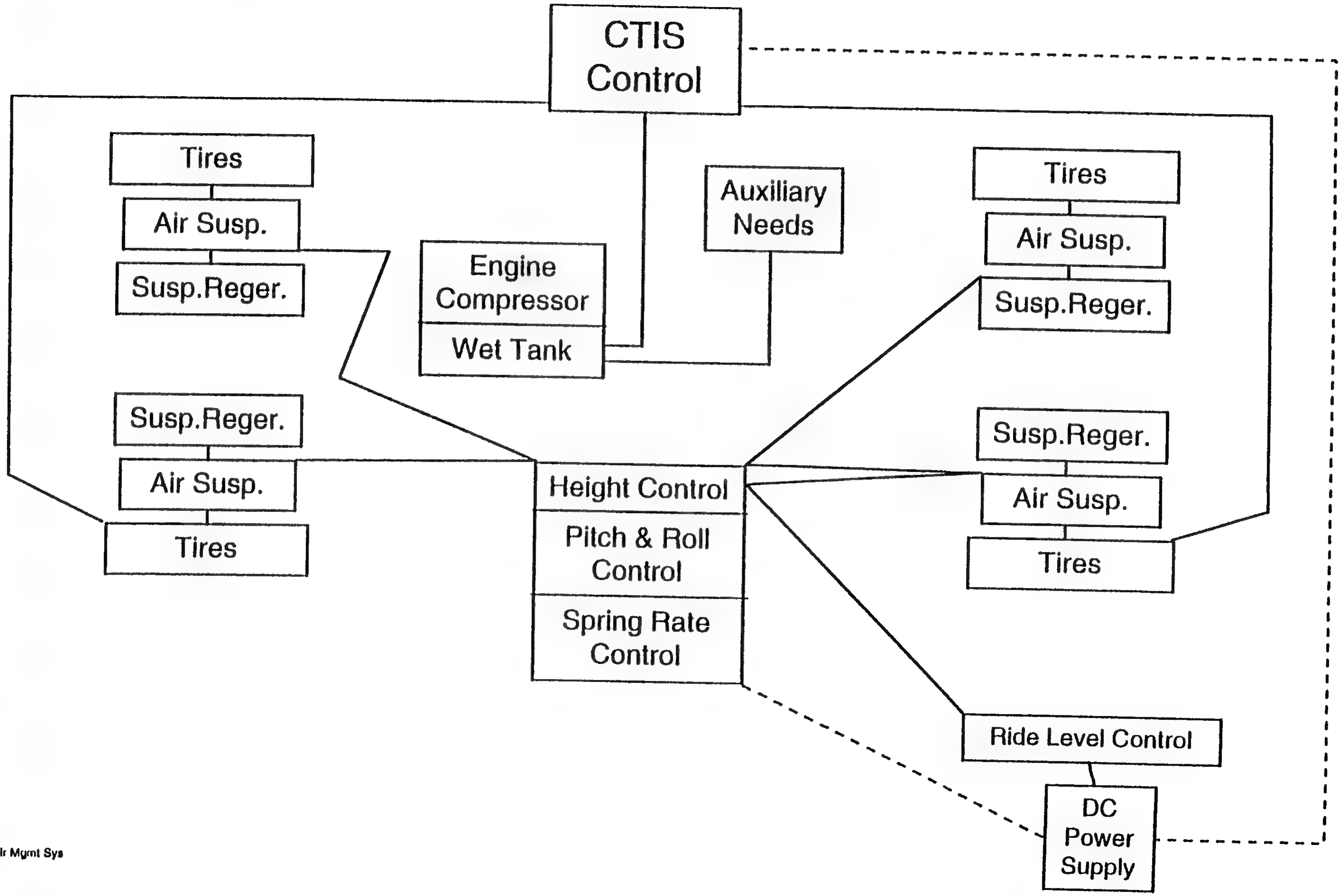
# RSTA-V AIR MANAGEMENT SYSTEM



## Hull Subsystem Concept Description

The hull subsystem provides the platform structure enclosure and protection for payload and onboard systems. The subsystem consists of: frame, cab, armor, covers and grills. The hull design goals are as follows:

-maximize internal volume
-up to 6 person crew size
-exterior cross section 65" x 66"
-minimize weight
-maximize structure strength
-support double "a" arm suspension concept
-minimize vehicle signature

## Hull structures and estimated weight

The hull weights presented in the vehicle weight estimates are extrapolation from the tubular hull designs described in the HTMMP and JTEV reports. During the second of half of this study, GDLS will pursue an optimal hull structure concept which best meets the desired weight target while supporting survivability, supportability and cost goals. The following comparison of alternative hull structure concepts shows tubular steel and advanced composite as the lightest approaches. The analysis also shows the severe weight penalty associated with providing full ballistic protection to the crew.

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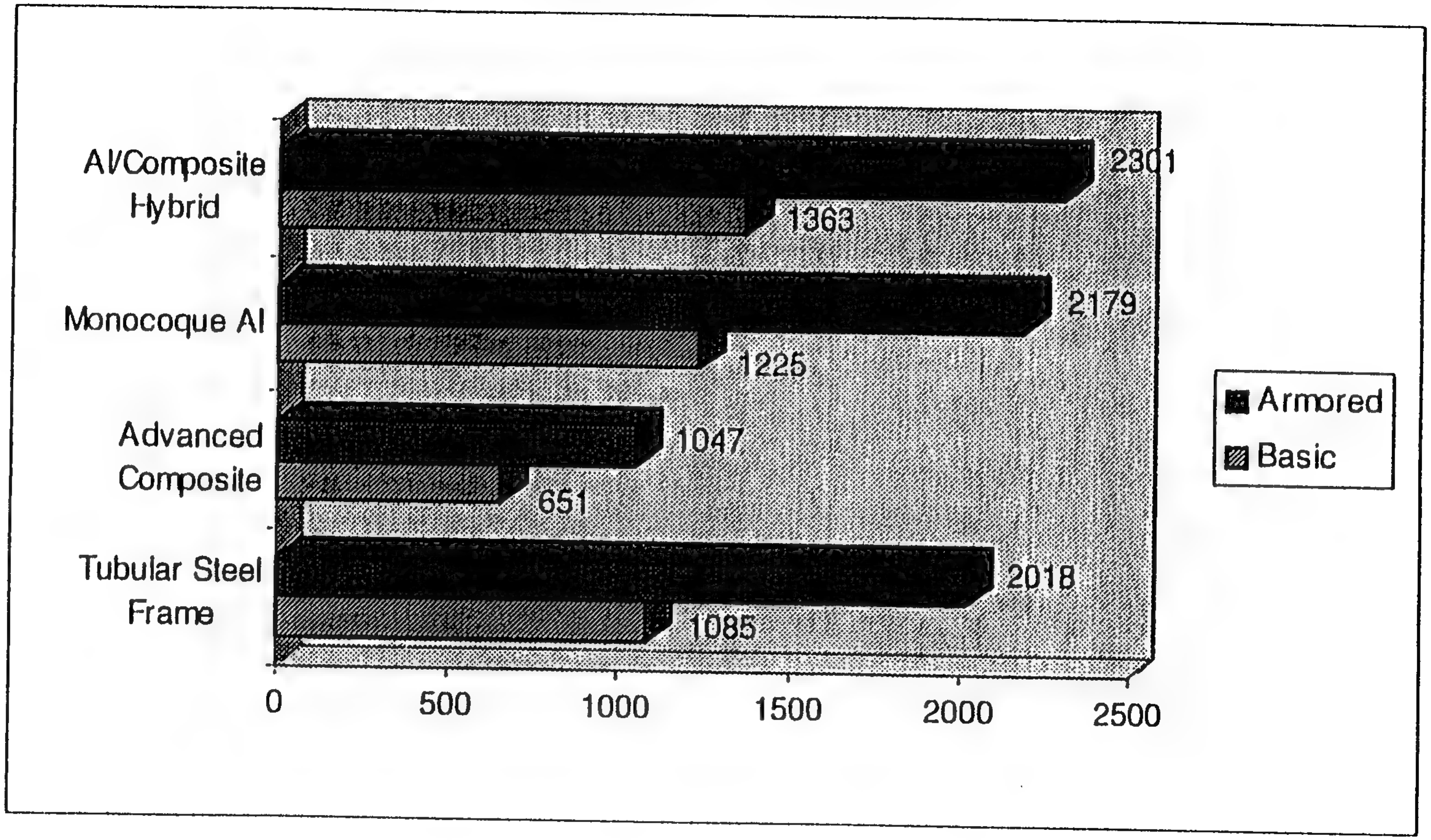
# Hull Structure Alternatives



# Electrical Subsystems

## RSTA-V Electrical Subsystems Concept Description

The three Electrical Subsystems envisioned for the RSTA-V are the Drive Train subsystem, the Control and Display subsystem, and the COM/NAV subsystem. The Drive Train subsystem consists of everything necessary to convert primary power at the shaft of the engine to mobility tractive forces, and includes the electrical power generator attached to the engine shaft, the electrical energy storage devices, and the traction motors and controllers. The Control and Display subsystem consists of the entire man/machine interface excluding COM/NAV equipment. This would include, but not necessarily be limited to an accelerator pedal, a brake pedal, a start switch, an interactive operator's display panel, a vehicle control computing system, and the necessary data bus structure to enable the computing system to communicate with the individual controllers and actuators that comprise the Drive Train Subsystem. The COM/NAV subsystem is comprised of the external radio communications devices and the vehicle attitude and position location unit.

The primary thrust of the effort to date has been spent on the Drive Train subsystem. General Dynamics Land Systems is currently engaged in the Abrams Systems Enhancement Program to provide enhanced capability for the M1A2 Abrams Main Battle Tank in the areas of control displays, computing devices, memory storage devices, and data bus technology, and it is intended that the RSTA-V program benefit from this activity rather than duplicate it Therefore, the remainder of the Electrical Subsystems briefing will speak very little to this subsystem.

Similarly, the COM/NAV area will not be elaborated other than to say that it is anticipated that the Navigation unit will be an attitude and heading reference system coupled with GPS to establish position and the COM equipment will likely consist of one or more SINCGARS radios.

## Electric Drive Train Goals

Among the benefits of an electric drive train are enhanced power management, independent wheel traction control, improved fuel economy, improved stealth capability, improved burst acceleration, drive train mobility/flexibility, and propulsion drive redundancy.

The ability to store power electrically permits putting the right quantity of power where it is needed when it is needed. With a separate motor for each wheel, the tractive force for each wheel can be controlled independent from the others. If one wheel is in the slippery mud, that wheel would be supplied with only the torque which it can usefully accept. Similarly, when braking on slippery surfaces, the potential exists for incorporating anti-skid braking. Each wheel position and angular velocity is typically sensed as a requirement for the drive system. These parameters can be compared with the vehicle velocity to determine if traction has been maintained.

The subject of improved fuel economy is still being studied. An electric vehicle is not inherently more efficient than a mechanically driven one. Indeed, if two vehicles of identical weight, one being a hybrid electric and the other mechanically driven happen to be travelling on a hard level surface at the same pace, if the speed is such that the mechanical engine is running near its optimum fuel economy point, it will likely beat the electrical vehicle in terms of fuel economy.

On the other hand, improved fuel economy in a hybrid vehicle is potentially available from three sources: (1) the potential for installing a smaller engine that meets the vehicle's average power needs, supplementing the engine power with "burst" power from an electrical energy storage system, (2) the potential of recovering some of the kinetic energy of motion through regenerative braking rather than wasting it all as heat, and (3) the potential for running the engine only at its "sweet spot" of optimum fuel economy.

Consider the first of these potential savings as it applies to a military vehicle. Such a vehicle designed for off-road use has special problems not encountered in a typical hybrid vehicle designed primarily for road transportation. The engine size will be dictated by the largest continuous steady state requirement for power, which in the case of a military off-road vehicle might be a requirement to slog through thick mud or heavy desert sand hour after hour at some reasonable

speed. In contrast, the maximum output capability of the E-Drive system will be determined by the largest intermittent power requirement, such as accelerating the vehicle. Between the steady state and the intermittent capabilities lies the gray area of the "quasi-steady state" power requirement. Like the intermittent loads, these loads would be supplied by a combination of generated and stored power, but the duration for these loads is on the order of minutes rather than seconds. If improved fuel economy through the use of a smaller engine is of primary importance, the specification must carefully limit the duration of these "quasi-steady state" loads in order that the correct balance between engine size, battery storage, and intermittent storage be obtained.

Energy recovery through regenerative braking is also an issue and will be addressed in more depth later in the report. As for the third item above, that of running the engine at its "sweet spot," the mission profile will again have a profound effect on the fuel savings encountered. If the mission favors those situations where a mechanically driven system would operate near its "sweet spot," then the fuel savings would likely be negative rather than positive. Unfortunately, those missions not specifically favoring the mechanical solution will tax the electrical solution as well.

The electric drive also provides the ability to operate in a stealth mode without the engine running for those situations that require the absolute minimum noise signature. A tradeoff must be made between burst acceleration capability and distance travelled in stealth mode, as the energy storage devices that favor each of these objectives compete for space and weight budgets as will be elaborated later in the report.

Drive train modularity and design flexibility is maximized with an in-wheel electric drive train. The same unit can be used in a 4x4, 6x6, or other vehicle layout. Potential exists for use with an electrically driven trailer as well.

Unlike mechanical systems, where failure of a single component can easily render the vehicle immobile, a hybrid system could remain mobile after the loss of the main engine or many other combinations of parts such as a motor controller or wheel drive unit. This represents a significant advantage of the electric drive train in terms of propulsion/drive train redundancy.

# Power Architecture Goals

- Power Management
  - Peak Power (Capacitor + Generator) 236 kW
    - Provides acceleration performance
  - Sustained Power 142 kW
    - Provides speed on 10% grade, and determines engine size
  - Silent Running
    - Burst 140 kW
    - Sustained 10 kW
  - Silent Watch 0.6 kW
    - Runs candidate sensor suite
  - Regenerative Braking 70 - 140 kW
    - Regenerative Braking discussed in more detail on later slide
- System Management
  - These items also discussed in more detail in later slides
    - Engine Starting
    - Power Steering
    - Cooling

## RST-V Power Architecture Concept

A 28v Bus is still necessary for military vehicles because of the NATO starting requriement, legacy loads such as lights, radios, etc., and the fact that the sensor suite is likely to run on 28v. The 28v bus is stabilized by a 28v battery, charged through a down converter from the HV bus. The NATO connector attaches to this bus, and can start the vehicle through an up-converter if the high voltage system is discharged.

A High Voltage bus is necessary for the traction motors, as 200hp at 28 volts is over 5000 amps. The payload would be all busbars. The subject of how high the high voltage should be will be addressed shortly.

A Control Display unit is shown as well as a vehicle control computer. The system data bus is omitted for clarity of the drawing. It will connect the vehicle control computer with all of the individual controllers shown. This bus would be selected during vehicle design based on vehicle simulation, and would likely be a combination of discrete signal wires and one or more multiplexed signal buses.

The operator inputs such as the accelerator, start button, brake pedal, etc. are also omitted for clarity. These would interface directly with the control computer except for those that during the design phase are chosen to be incorporated in the control display unit.

Large military vehicles demand voltages near the 800 - 1000 v limit of current IGBT technology. Although existing IGBT modules can withstand 1700v, margins for spikes and back emf surges must be maintained.

The automotive world seems to be headed for moderate voltages in the 250 - 350v range, as parisitic packaging losses in batteries and capacitors increase as voltage increases. Safety also becomes increasingly challenging with increasing voltage. The 350v shown is adequate for an 8000lb class vehicle, and accommodates use of a high voltage battery or capacitor. The selection of a voltage for the high voltage bus remains open, however, because one wheel motor candidate (Magnet Motors) still favors an 800v system.

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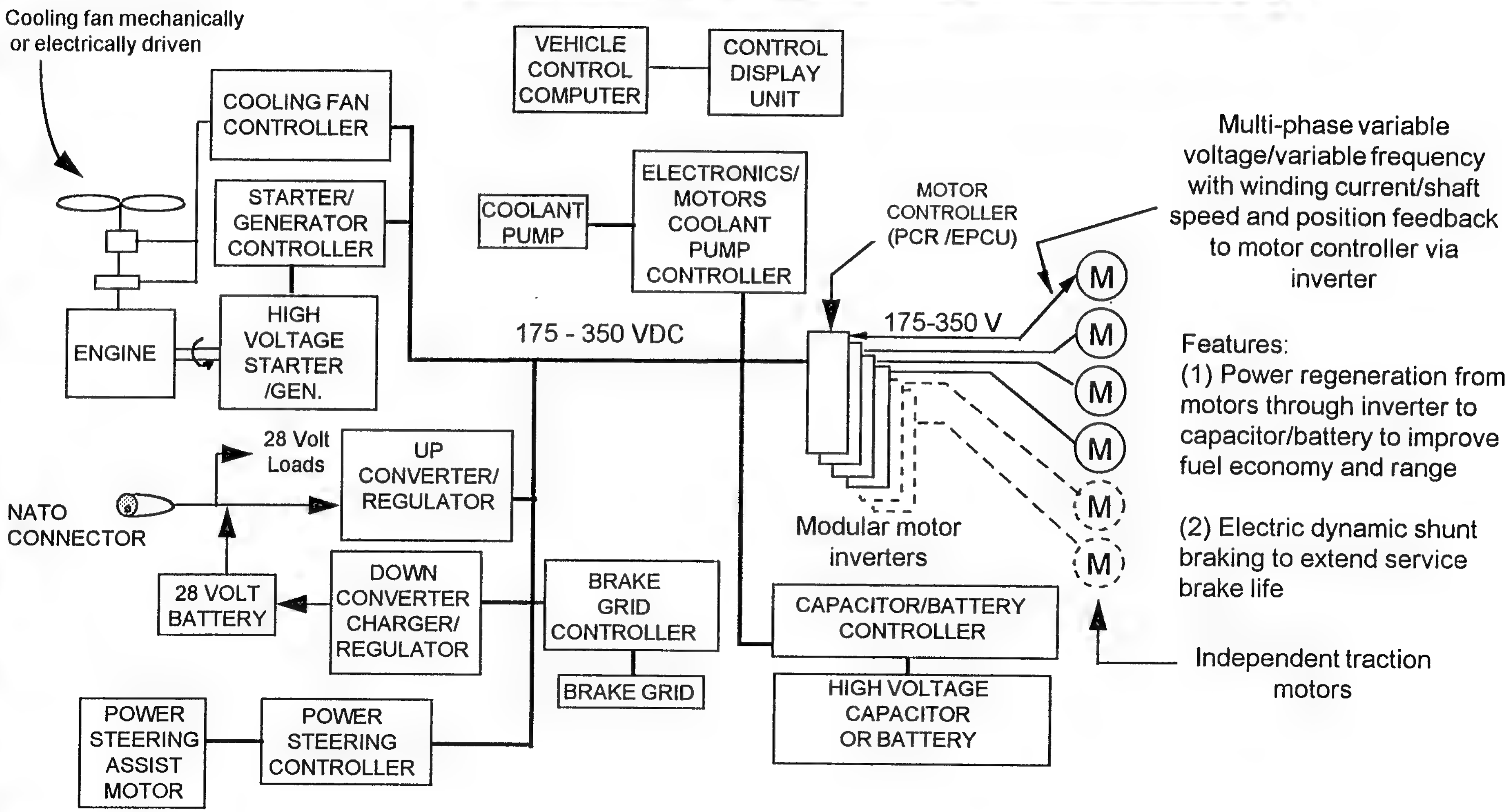
# RST-V POWER ARCHITECTURE CONCEPT

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## Energy Storage Alternatives for Burst Power

A hybrid electric vehicle can incorporate a high power energy storage device to supplement the engine during periods of acceleration and to quickly store energy obtained from regenerative braking. The near-optimum device for this from a performance standard is an energy storage flywheel. These devices have demonstrated power capability in the 500hp range and energy storage capability in the 80 MegaJoule (MJ) range for large vehicles.

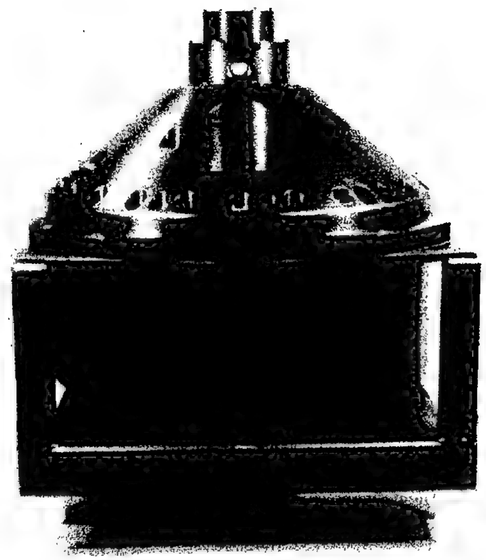
Unfortunately, the device has certain characteristics that eliminate it as a candidate for RSTA-V. Similar to the engine, the form factor is rigid in that space for the device must be "carved out" of the cargo area, rather than tucked away in some otherwise unusable space. The device is also dangerous without some form of containment armor to protect vehicle occupants from fragments should the flywheel happen to fail. Although this risk is being vigorously attacked by industry, it does not appear likely that it will be solved in time for use on this vehicle.

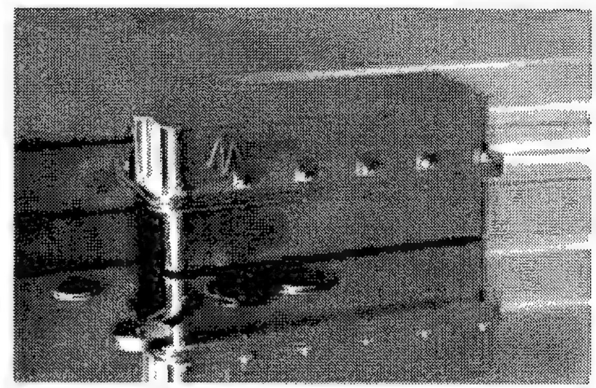
The Ultra Capacitor from Maxwell Balboa appears to be arriving just in time for RSTA-V. A useful device is built up from 140 of the units shown. Similar to the way a high voltage battery is constructed from individual cells, the 3 volt, 2300farad units are connected in series to create a 185lb, 16.4 farad, 350v device that can deliver a 190hp burst for 2-3 seconds or 126hp for ten seconds. It would hold 0.75MJ of useable energy, and would hold its charge for several days.

The usage strategy would be to keep it full when stopped to have an acceleration burst available, and to float the voltage at a point between 175 and 350v at a point where the maximum amount of kinetic energy could be recovered through regenerative braking.

If the capacitor proves impractical or otherwise undesirable, the space claim currently reserved for the capacitor would be converted to store a high voltage battery. This would enhance the range under electric power alone and would improve the silent watch capability. However, the acceleration capability and the regenerative braking capability would be negatively impacted.

# ENERGY STORAGE ALTERNATIVES FOR "BURST POWER"





FLYWHEEL FEATURES

- High Power
- Moderate Storage
- Rigid Form Factor
- High Risk ... Safety

ULTRA-CAPACITOR FEATURES

- High Power
- Low Storage
- Flexible Form Factor
- Low/Moderate Risk

## Battery Technology - Power Density

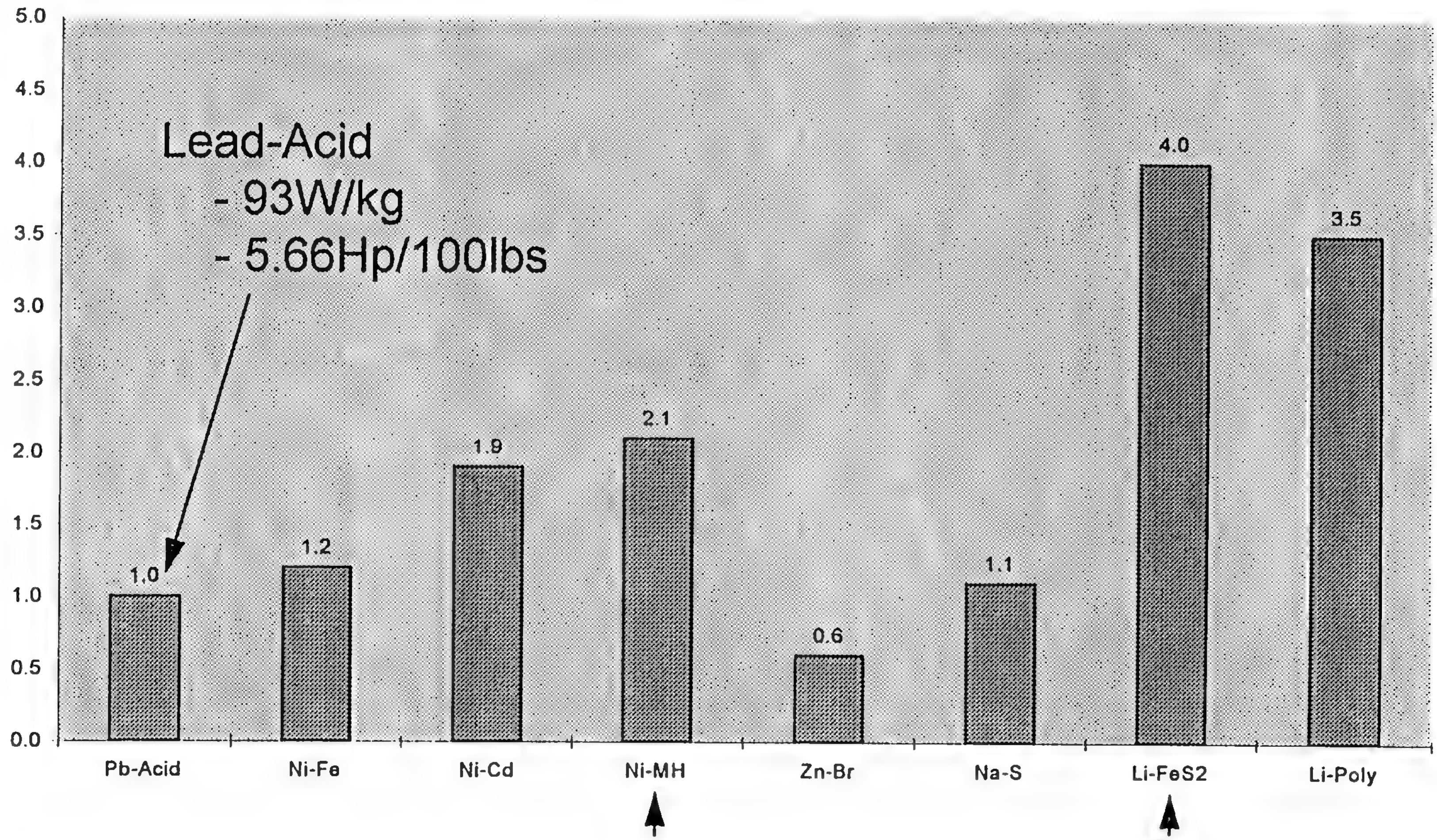
This chart shows the relative peak power density of a variety of battery chemistries. Recall that the power capability of a battery relates to the speed at which energy can be inserted and removed from the battery, and therefore relates primarily to its ability to contribute "burst" acceleration capability and to store recovered energy from regenerative braking.

The lead acid battery is shown on the left, and the remainder of the chart is normalized to this chemistry. The information from this chart was obtained from a chart in the "Automotives Electronics Handbook" published in 1994 by McGraw Hill. A more recent informal analysis performed in-house on the acceleration performance of the General Motors EV-1 indicates that the power handling capability of their lead-acid battery may actually be about twice that shown here, more in line with what is shown for the Nickel-Metal Hydride battery, which may explain why the Nickel-Metal Hydride chemistry was not chosen for the EV-1. The numbers shown here for lead acid are representative of the current standard military 6TL battery.

The Lithium based battery chemistries currently show the most promise, but are currently not available for EV use. With the announcement of the Toyota EV, it is still possible that this technology might be ready in time.

The automotive industry is vigorously pursuing battery technology to support the potential electric car market. The current weight allocation of 145lbs covers the two military batteries, and the space claim allows room for two more. If an alternate battery chemistry becomes practical and cost effective, it can be readily inserted in place of the military lead acid batteries. It is interesting to note that General Motors retained the lead- acid technology for their recently introduced EV-1 vehicle.

# Battery Technology
# Relative Peak Power Density



**Battery Technology - Energy Density**

The relative energy density of a battery relates directly to the range of the vehicle under electric power alone. Eight thousand pounds moved down a paved level road translates to about one MJ of energy consumed per mile. The information for this chart also comes from the "Automotive Electronics Handbook" previously cited, and would relate primarily to standard military lead-acid batteries.

Again, the Lithium battery shows great promise for the future.

Incidentally, it turns out that one of the significant problems with the Nickel Metal Hydride battery is its rather high self discharge rate, on the order of 20 - 25 % per month as compared to 5 - 10% per month for lead acid.

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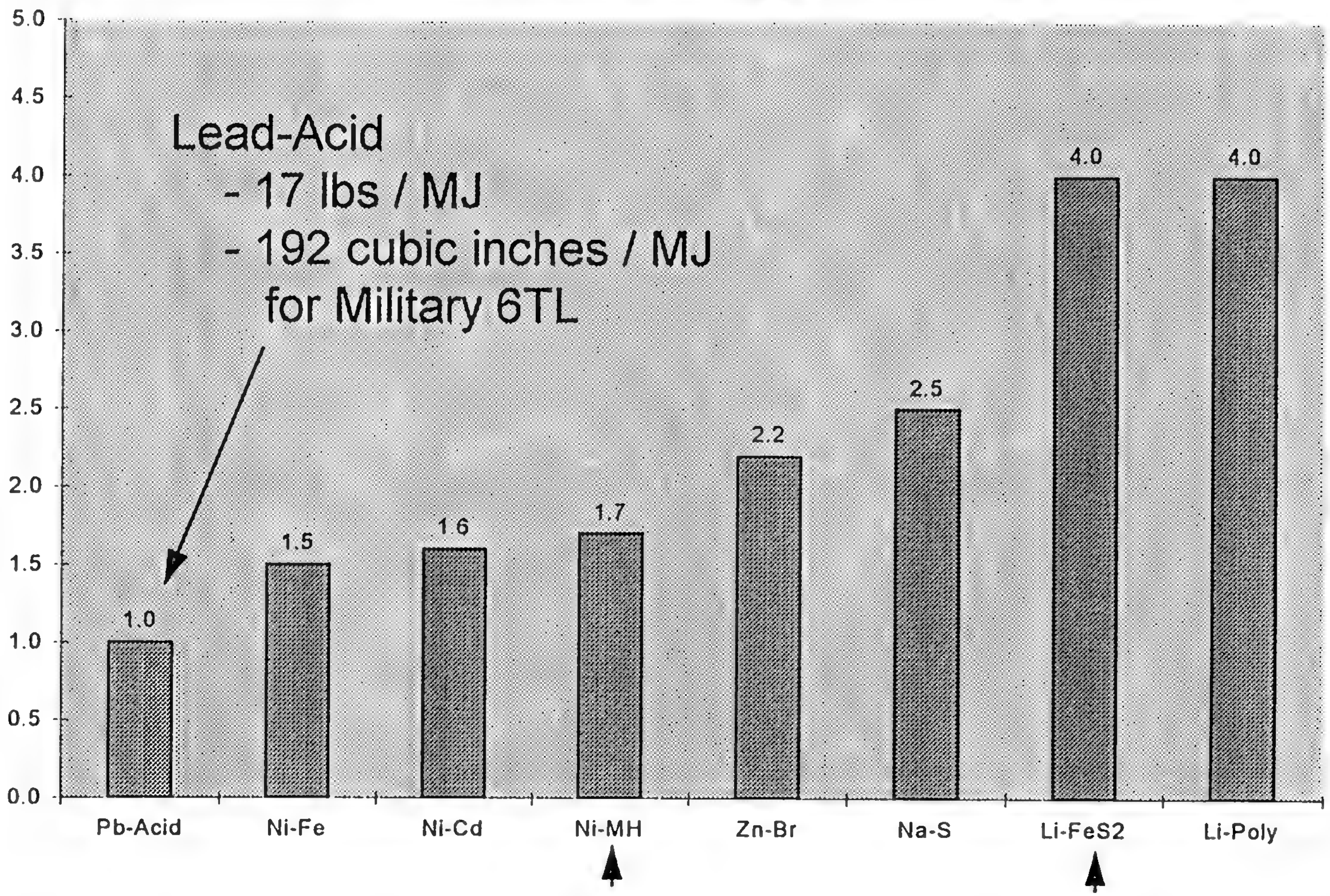
# Battery Technology
# Relative Energy Density



## Distance Traveled for 145 lb Battery

A hybrid electric vehicle requirements issue is how far the vehicle should be able to travel under battery power alone. This chart shows the distance traveled on batteries for the three main contenders in battery technology. The 145lb allocation shown was used since it represents the approximate weight of the two standard military 6TL batteries used to stabilize the 28v bus. In addition to comparing the battery chemistries, the chart vividly illustrates the significant effect on range of off-road travel in high rolling resistance terrain. As a vehicle travels through sand or mud, significant quantities of energy are used just to rearrange the soil. This energy is not recoverable through regenerative braking. Again, the key numbers for 8000lbs are about one MJ per mile for level hard surface, and about 6.67 MJ per mile for heavy slogging through 10% rolling resistance terrain.

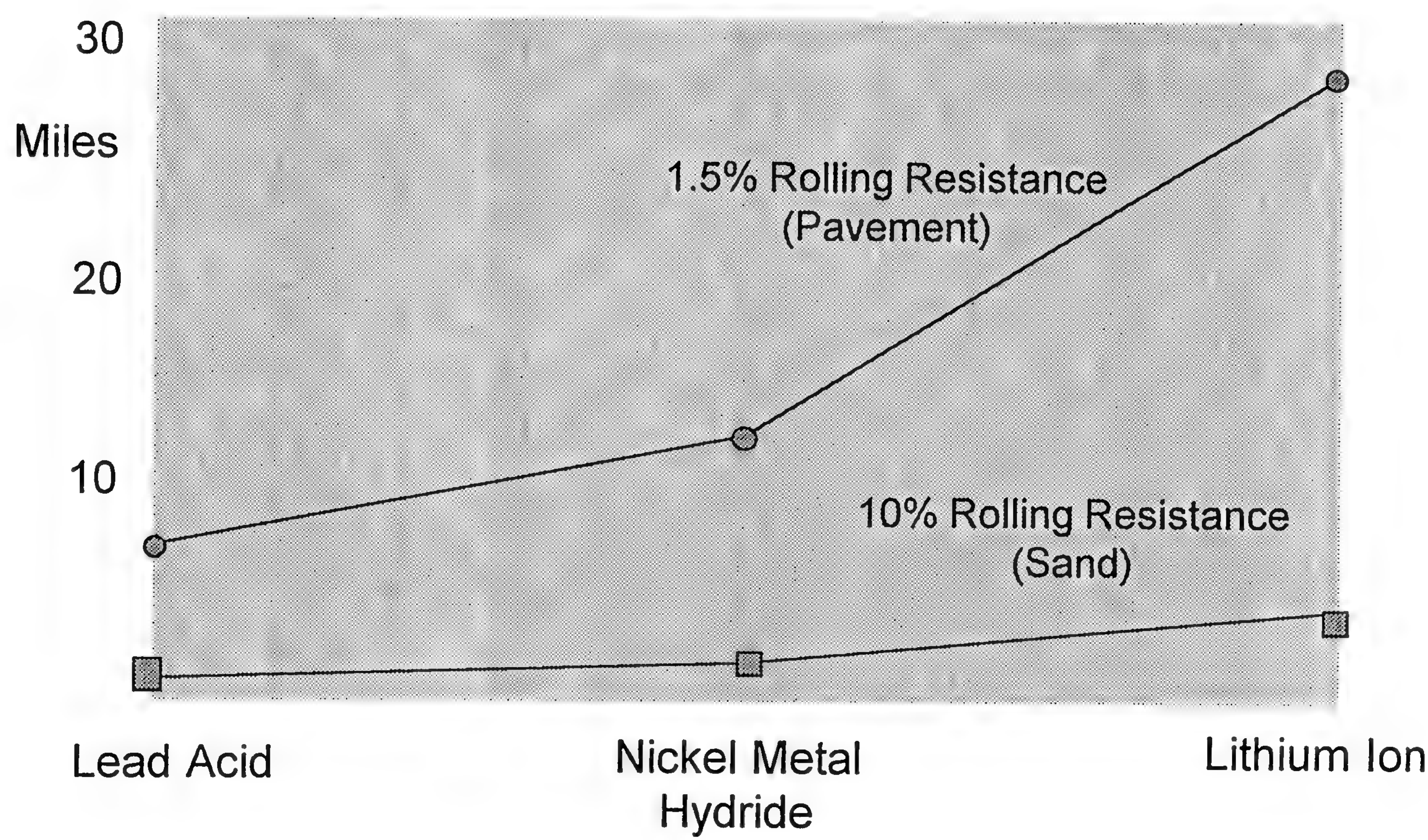
## Engine Starting

An engine that is expected to run silently must also be started silently. The starter-generator employed is a 200hp device with ample torque to start any of the engines considered. The starting current would be switched by the IGBTs in the generator controller, and hence there would be no contactor noise. The energy could be drawn from a capacitor, a high voltage battery, the 28v battery through an up converter, or through the NATO slave connector through an up converter.

In a silent watch mode, the 300 to 500 watts necessary to run the sensor package could be drawn from the capacitor during those periods where absolute silent operation is not required. The capacitor could supply the load for a half hour or more. The advantage of drawing from the capacitor is that it could be replenished by running the engine for only about 24-25 seconds, whereas battery charging typically requires charging times on the order of minutes rather than seconds.

If mission circumstances change and even the quiet operation of the engine is prohibitive, some energy could be transferred from battery to capacitor to replenish it in preparation for silent departure.

# Distance Traveled for 145 lb Battery



## RSTA-V Regenerative Braking

The problems of regenerative braking are illustrated on the following chart, together with the benefits of the capacitor in recovering reusable energy. The speed of the vehicle in miles per hour is plotted on the Y axis together with the kinetic energy of the vehicle in Mega-Joules at the time of the onset of braking. The kinetic energy "trajectories" of several types of stops are shown, including a 0.5g power stop from 60mph and three more typical 0.3g stops from 60, 50, and 40mph.

The capacitor and battery lines show the ability of these devices to absorb power in the braking operation. Since the rate of change of energy is power, a straight line corresponding to 320hp has been included. It is anticipated that this will be the approximate intermittent power capability of the wheelmotors on the vehicle. Any operation in the region above this line exceeds even the intermittent capacity of the wheelmotors, and therefore the traditional service brake must be employed. This energy would be lost to heat. The region below the 320hp line but above the sum of the capacitor line and the battery line represents that area in which the wheelmotors are capable of providing the braking torque, but the energy storage devices are not capable of absorbing all of the electric energy produced, and the excess energy would have to be dumped into the electric brake grid. This energy is also lost.

Note the space between the battery line and the capacitor line. This space represents the energy that can be recovered using a capacitor that would normally be lost if the vehicle contained batteries alone. Even with the best batteries currently on the horizon, it is clear that the capacitor recovers significant additional energy from regenerative braking. Note especially that the efficiency of the capacitor allows for recovering and reusing all but 5% of the energy for the slower speed stops that represent the more normal anticipated operation of the vehicle.

When the vehicle accelerates, the "burst boost" from the capacitor matches the acceleration profile nearly perfectly. When the capacitor is full, it can deliver its maximum power (190hp initially). As the vehicle accelerates, the voltage is drawn down until when the capacitor is at half voltage (considered empty, but still containing 0.25MJ) it is capable of delivering about 94hp. The boost can be tapered according to the position of the accelerator pedal.

Note that the burst capability of the capacitor is significantly higher than that available from the battery, although when the Lithium battery technology comes on line, the difference will be less significant.

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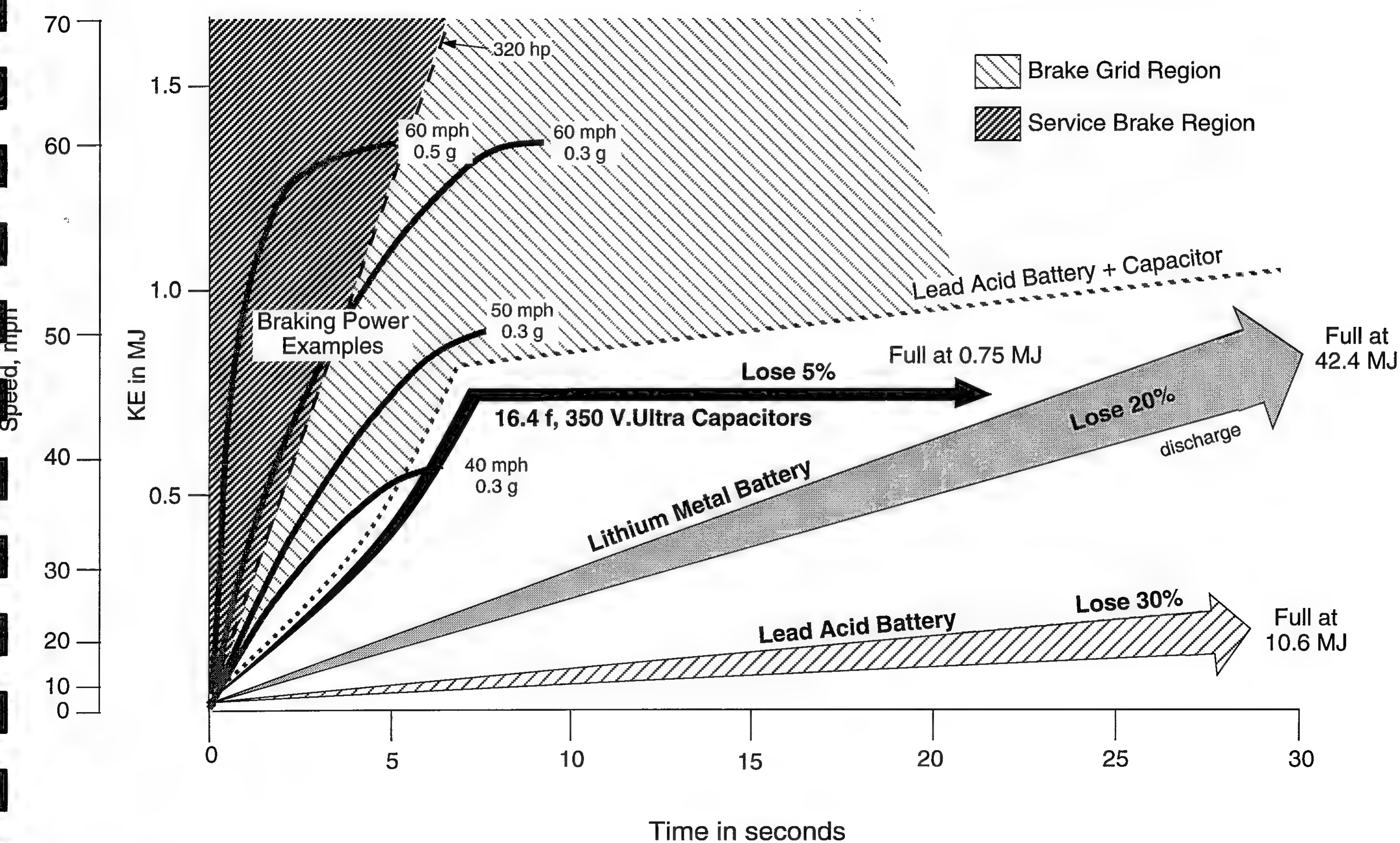
# RSTA-V REGENERATIVE BRAKING ENERGY RECOVERY



## Silent Running

The approach being promoted is that of providing an extremely quiet, low signature power plant that permits the vehicle to maneuver with stealth with the engine running. It is felt that if robust performance is required such as for hasty departure, the engine could remain operating.

Nevertheless, for those occasions requiring the absolute quietest possible operation, a minimal mobility capability would be available from the stored energy in the battery and capacitor. The capacitor would provide the burst 120 - 190 hp necessary to negotiate obstacles, while a 9.6kW up-converter would provide an average of 12 - 13 hp that would enable the vehicle to move with maximum stealth. This power would permit up to 5 mph average speed over 10% rolling resistance terrain, and up to 35 mph average on pavement.

As soon as the region requiring maximum stealth has been traversed, the engine can be silently started and the mission completed with the engine running.

## When Vehicle Not in Use

Between periods of use, the capacitor would be kept charged just like a battery. A monitor designed with extremely low power CMOS semiconductor technology would check the capacitor voltage periodically, moving energy from the battery to the capacitor to replace leakage. The vehicle must be run at least every few months to maintain battery charge.

## The Umbilical Tow Concept

The hybrid electric vehicle offers an extended capability for assisting a vehicle with a disabled powerplant. The NATO connector is a 28v connector specified at 500 amperes for 10 minutes. The concept up-converter at 9.6kW would draw about 350 amperes. Rather than towing the disabled vehicle, which might be impossible due to terrain mobility considerations such as deep mud, snow, or sand, a cable long enough to allow the two vehicles to follow one another could be used to transfer sufficient power to the disabled vehicle to allow it to move through the terrain using its own electric wheel motors.

**Safety Considerations**

If the entire power bus is allowed to "float" and is tied to ground only at one place through resistors in the megohm range, then a person simultaneously contacting both ground and either side of the bus would only feel a slight tingle due to the few microamps that would flow. Such a fault would be detectable by the ground fault interruption (GFI) system, but even if the GFI were defective, no harm would be done.

Alternatively, if either side of the bus is grounded, or if both sides are "stiffly" maintained at plus and minus one half the voltage, then a person contacting one of these rails and ground would be dependent on the swift action of the GFI in order to stay alive.

Access panel interlocks could be used to ensure that personnel could not be subjected to electric shock while working on the vehicle. These interlocks would not be required to switch the load current, but rather would serve to physically disconnect the device being worked on from the power source. This would be similar to the National Electrical Code for building wiring, which requires that every electric motor have a physical disconnect device within sight of the motor so that personnel working on the motor can be assured that it is disconnected.

Markings and warning labels would be used liberally. The entire high voltage system would be encapsulated for immersion in salt water. The capacitor and/or high voltage battery would be broken into smaller, non-lethal units for disassembly.

These concepts notwithstanding, constructing a safe electric military vehicle remains a significant design challenge, and will require the expenditure of a fair amount of effort.

**Candidate Traction Motor Characteristics**

This chart shows the results obtained from a request for information sent to electric traction motor vendors. Only the Magnet Motor response was complete in that it met the torque requirements and fit the space claim. Their response also included detailed sizing for the electronics packages and was therefore chosen in the weight and space claim charts shown previously.

The Kaman Electromagnetics solutions also showed some promise, but did not include a service brake within the space claim.

Unique Mobility solutions would not fit the space claim. Their motors apparently still have the stator outside the rotor, and although they obtain good motor characteristics with their design, they do not generate the high torque densities that are appropriate for this vehicle.

Similarly, the SatCon previous traction motor experience has been primarily with induction motors, although they do have a solid grasp of the issues. Their design assistance and eagerness to participate were helpful in coming up with the two motor design presented on a later slide.

# Candidate Traction Motor Characteristics

| Vendor | Approach | Torque (Ft-Lbs.) At Hub | Motor Weight (Lbs.) | Hp | Diameter (inches) | Length (inches) |
|---|---|---|---|---|---|---|
| Kaman Electromagnetics Corporation | 36cm Radial Gap Permanent Magnet Motor with 12:1 Gear Ratio | 3319 | ~100 (w/o. gearbox) | >40 | 17.56 | 7.62 |
| Kaman Electromagnetics Corporation | 20cm Radial Gap Permanent Magnet Motor with 12:1 Gear Ratio | >3000 | ~100 (w/o. gearbox) | >40 | 16.7 | 5.3 |
| Magnet-Motor GmbH | Radial Gap Permanent Magnet Motor with 6:1 Gear Ratio | 3024 | 143 (inc. gearbox) | >40 | 18.11 | 6.69 |
| SatCon Technology Corporation | Radial Gap Permanent Magnet Motor Direct Drive | 2490 | 297 (w/o gearbox) | 79 | 18 | 8 |
| SatCon Technology Corporation | Radial Gap Permanent Magnet Dual Motor Drive | 2504 | 203 (hub assembly) | >40 (up to 125) | 18 | 8 |
| Unique Mobility, Inc. | Radial Gap Permanent Magnet Motor with 6:1 Gear Ratio | 1650 | 90 (motor only) | 84 | 10.5 | 8 |

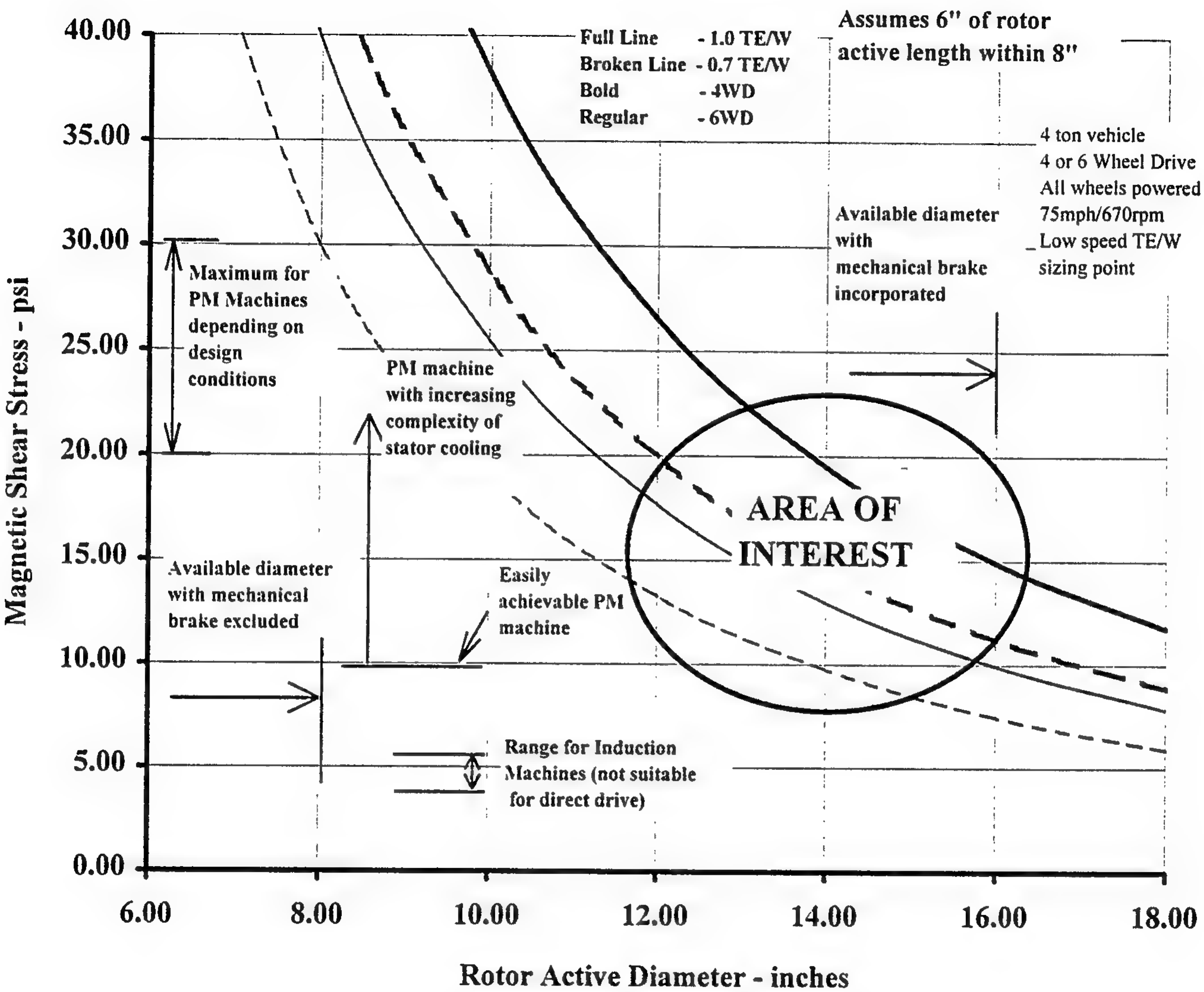
**Magnetic Shear Stress in Electric Traction Motors**

This chart was provided by SatCon and shows the challenge presented by In-Hub wheelmotor design. The action of an electric motor is produced by the development of a magnetic shear stress produced at the gap between the rotor and the stator by the interaction of the currents flowing in the windings and the magnetic field existing there. This magnetic shear stress can be considered somewhat of a figure of merit for the motor, with higher values within a specific motor type requiring special design considerations such as rotor cooling, etc.

The shape of the motor gap together with the magnetic shear stress generated can be used together for rough paper and pencil designs that identify the potential capability of an electric machine fitting a certain space claim. It is obvious that since torque in the motor will be produced by this shear force acting on the gap radius as a lever arm, large gap diameter (read on the chart as large Rotor Active Diameter) produces large torque.

The permanent magnet machine provides the highest torque density of available motors. Recent advances in magnetic materials technology have made the latest materials such as the Neodymium-Iron-Boron compounds less sensitive to heat. Furthermore, their extensive use in the medical electronics industry has brought production capability on line to the extent that it is now the material of choice for permanent magnet machines.

The Magnet Motors approach of using a multi-pole configuration with a cup shaped rotor riding outside the stator has achieved the highest magnetic shear force and the resultant highest torque density of all the motors surveyed. It appears that Kaman has abandoned somewhat their axial gap approach in favor of this same concept, but Magnet Motors still is providing superior torque density at this point.




REQUIREMENTS FOR IN-HUB DIRECT DRIVE

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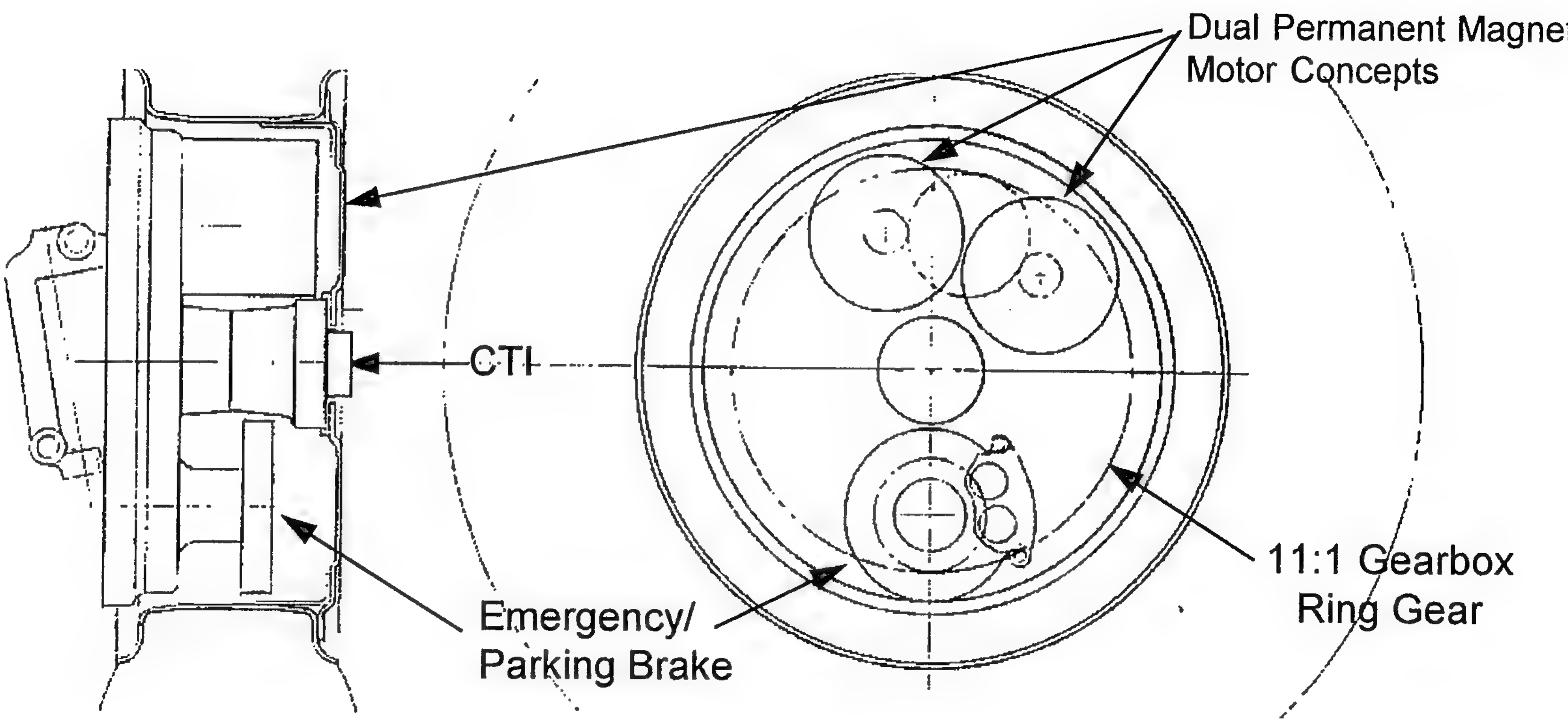
FIGURE 1

## RSTA-V In-Hub Dual Motor Concept

This chart shows a concept developed in-house using two smaller identical permanent magnet motors in each wheel. A large ring gear in the housing at the left is driven by two motors connected in parallel. A third gear meshes with the ring gear and drives a service brake/parking brake rotor. With each motor producing 114 ft lbs of torque and the 11:1 gear ratio shown, the wheel torque calculates to 2508 ft lbs. The motors could be driven by the same set of electronics since they would be rigidly coupled in angular position by virtue of the gearing.

The concept features easy access to individual components for service and repair.

# RSTV In-hub Motor Concept
# Dual Motor Concept




Max. Torque @stall: 2500 ft.lbs, Max. Speed 75 MPH

## RSTA-V Concentric Motor Approach

The appropriate international trade agreements and licenses are not yet in place to provide detailed drawings of the Magnet Motors design. Nevertheless, this chart shows their concept as best that can be gleaned from extensive telephone conversations.

The stator is supported by the spindle in the center of the hub, and the electric and cooling lines go through the center of the spindle. The cup shaped rotor rides on bearings supported by the spindle and the rotor passes its power to the planetary gear through a pinion protruding to the left of th rotor, into the gearbox. The open part of the rotor cup opens to the right, slipping over the stator. The gap is thus radial, and of maximum diameter. The entire case rotates with the wheel, being driven by the output of the planetary set. The service brake is exterior to the case, as shown in the diagram.

## Magnet Motors In-Hub E-Drive Experience

Magnet Motors has considerable experience with in-hub electric wheel drive systems, beginning with an unarmored 4x4 military testbed vehicle they constructed in 1986. They later built an 8x8 experimental military testbed which they have been using to demonstrate the advantages of individual wheel drive. Although they have not performed a full military qualification, it is only because they have not yet had opportunity. Much of the testing of this vehicle has been off-road.

They do have extensive experience in the commercial bus market, with 50-60 buses in service. The 12 buses in Switzerland are scheduled 19 hours per day over potholes, curbs, and cobblestones and have accumulated over 125,000 miles of service. The european bus environment should not be underestimated in its ability to tax and test the durability of the in-hub drive system.

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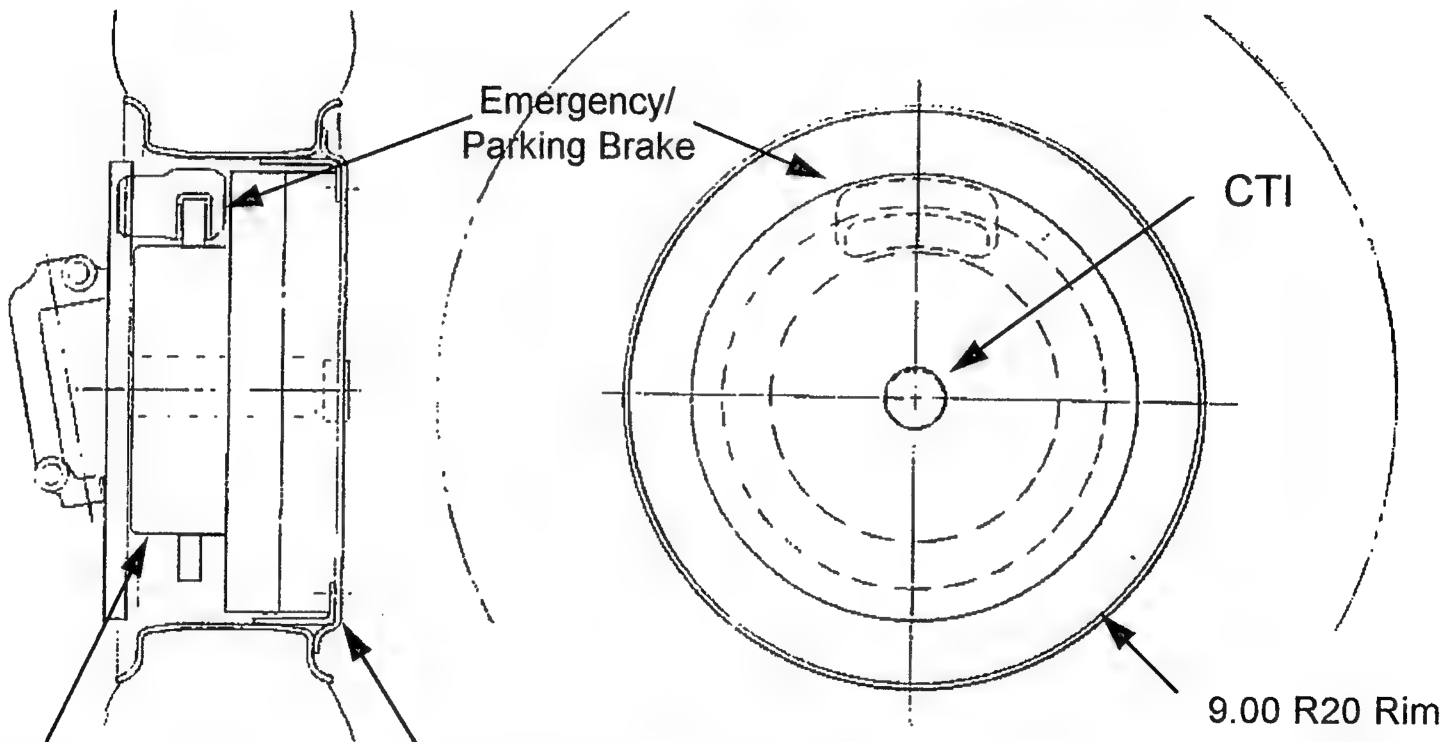
# RSTV In-hub Motor Concept
# Concentric Motor Approach




Max. Torque @ stall: 3000 ft. lb., Max. Speed 75 MPH

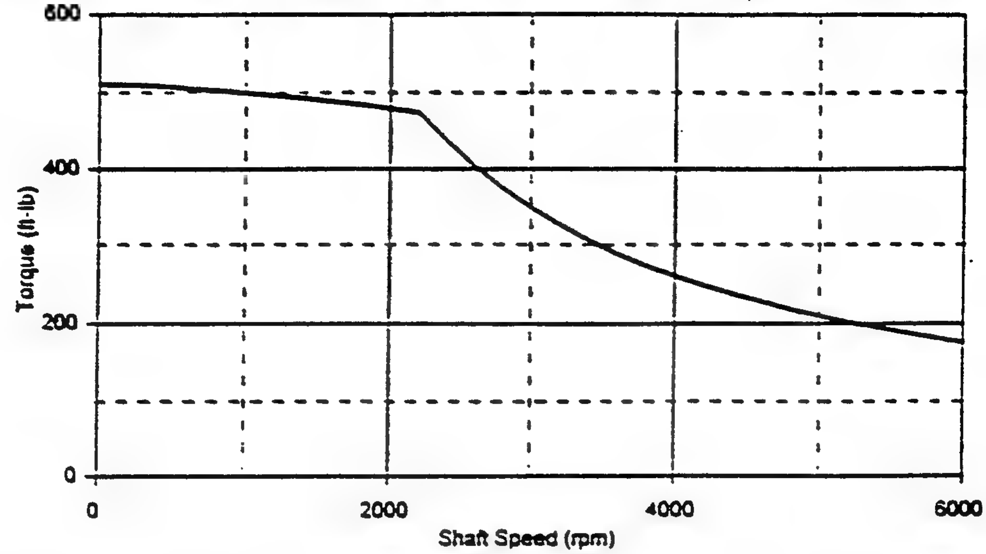
**Candidate Generator**

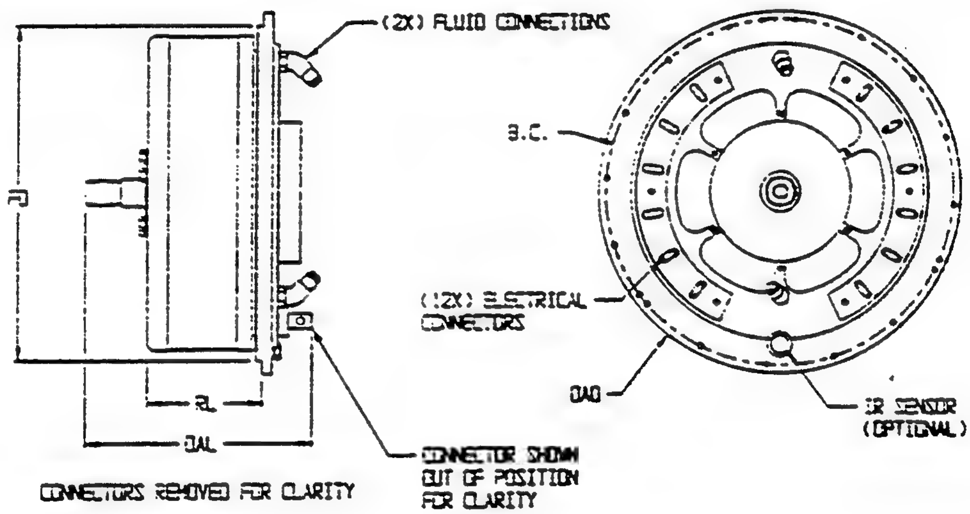
This chart shows the Kaman PC-36 machine as a candidate starter-generator for the RSTA-V. The device as shown generates over 500 ft-lbs of torque and 200hp, enough to start any engine under consideration. Its 150kW rating also matches the engines under consideration.

Note that it is shown only to demonstrate the size and capabilty desired, and that an existing design is quite capable of doing the job. It is possible that the generator could be tightly integrated with the engine, with the rotor fastened directly to the engine flywheel, and the stator mounted directly to the engine housing, thereby saving both weight and space.

It should also be pointed out that the Magnet Motors device is similar in size, shape, and general design, and could be used as well. No Magnet Motors drawing was available.

PC36 Torque vs Speed




NOTE: Drawing is for illustrating basic motor dimensions and does not necessarily represent the actual appearance of the motor.

| Dimension in inches (mm) | | | | |
|---|---|---|---|---|
| FD | RL | OAL | BC | OAD |
| 16.75 (425.5) | 5.63 (143.0) | 11.22 (285.0) | 17.31 (439.7) | 18.06 (458.7) |

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## RSTA-V Electrical Subsystem Risk Assessments

The only significant risks are with the traction motors, the ultra-capacitor, and the electronics packaging, and all are considered low to moderate. Maxwell claims to have a large production contract for the electric vehicle industry already in hand, and is supposedly building production capacity as of this writing.

Of the motor vendors actually visiting the Muskegon Operations facility, SatCon appeared to have the very best state-of-the-art packaging for IGBT switching motor controllers based on the work they did for the Patriot program. They have a packaging technique that appears to put the semiconductor junction in the IGBT closer to the coolant by eliminating the IGBT case and mounting the chip directly into a custom package. The Magnet Motors proposal showed electronics packing densities almost identical to SatCon's , and Magnet Motors clearly leads in the in-hub high torque traction motor arena.

All the risks appear to be manageable.

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# RST-V Electrical Subsystem Risk Assessments

| Subsystem | Description | ATD 2000 | Production 2004 |
|---|---|---|---|
| Drive Train | | | |
| - Generator | Kaman PC-36 | Low | Low |
| - Traction Motors | New Design | Moderate | Low |
| - Capacitor | Maxwell Ultra-Cap | Low/Moderate | Low |
| - Electronics | New Design/Pkg | Low/Moderate | Low |
| Control/Display | Modified ASEP | Low | Low |
| Com/Nav | Sincgars/GPS | Low | Low |
| Sensor Suite | Computing Devices Canada | Low | Low |

# Specification Compliance/ Recommendations

| Paragraph Number | Title | Requirement | Compliance | Comments |
|---|---|---|---|---|
| 3.2.1.1 | Weight | Tabulated | Meets objective | |
| 3.2.1.2 | Mobility | | | |
| 3.2.1.2.1.1 | Forward Speed | 60(75) mph on dry, level hard surface. | >75 mph | Dry, hard surface assumed to have rolling resistance of 1.5% of GVW for wheeled vehicles |
| None | Cross Country Dash Speed | 50 mph on 0% grade. | Meets 45 mph | Not included in Draft Spec. Mission Profile suggests 50 mph on 0% grade, periodically. Spec should state rolling resistance (10%) and duration. |
| None | Speed in Mud or Sand | 15 mph on 0% grade with TBD on-board power demand. | >24 mph with 25 kW power demand | Not included in Draft Spec. "Power Demand" statement suggests 15 mph on 0% grade, continuously. Spec should state rolling resistance (15%) and power requirement of on-board equipment. |
| 3.2.1.2.1.2 | Dash Speed | 70(75) mph for 10(20) minutes on dry, level hard surface. | >80 mph | Can meet objective dash speed continuously. See objective forward speed requirement above. |
| 3.2.1.2.1.4 | Acceleration | 0 to 30 mph in 6(4) seconds and 0 to 60 mph in 15(10) seconds. | Meets objective | Dictates energy storage capacity. |
| 3.2.1.2.1.5 | Forward Motion | In 10 seconds | Meets objective | |
| 3.2.1.2.2 | Braking | Several | Meets objective | |
| 3.2.1.2.3.1 | Drawbar Pull | 0.40 TE/GVW after 1 inch of rainfall | Recommend 0.30 TE/GVW | This is a tire/track aggressiveness issue. From WES' Tracked vs. Wheels study, attainment of 0.4 TE after 1 in. of rainfall is not possible for wheeled vehicles, and improbable for tracked. 0.3 TE/GVW is more realistic. |
| 3.2.1.2.3.2 | Mobility Rating | Tabulated NRMMII performance | TBD | What is the basis for the values listed in the tables? If they are attainable by an existing vehicle such as the HMMWV they are reasonable goals. If they represent an advanced concept, further investigation is needed. |
| 3.2.1.2.3.3 | Terrains | Various | TBD | Objective definitions of the various soils are needed. Even with these, analytical predictions of performance may not prove to be accurate in practice. |
| None | Cooling | Not addressed | Meets | Cooling is not addressed. Vehicle should be capable of generating 0.6 tractive effort continuously on a 120 deg F day without overheating. |
| 3.2.1.2.4 | Obstacles | | | |

| | | | | |
|---|---|---|---|---|
| 3.2.1.2.4 | Longitudinal Slopes | Ascend 60% grade and ascend 5% grade at 40(60) mph. | Meets 60% and 60 mph on 5%, 40 mph on 10% | Draft Spec OK as far as it goes. But Mission Profile suggests 50 mph on 10% grade, periodically. Spec should state rolling resistance (1.5%) and duration. Mission Profile requirement dictates higher minimum engine horsepower. |
| 3.2.1.2.4.2 | Side Slopes | 15(25) mph on 40% side slope. | Will slide before tipping. Rmin = 36 ft @ 15 mph 99 ft @ 25 mph | Either the placement of the slalom pylons or a minimum radius of curvature should be defined along with the target speed to establish the desired acceleration. Alternatively, the intended lateral G acceleration itself could be specified. Ref. Item 7 |
| 3.2.1.2.4.3 | Vertical Step | Negotiate 15(18) inch step. | TBD | The required step height will exact a "TBD" price which may be significant. Give serious consideration to the importance of step height to mission performance. How high and how frequently are these steps expected to be encountered? |
| 3.2.1.2.4.4 | Fording | Ford 30 inch depth w/o kits, 60 inch with kit. | Meets objective | |
| 3.2.1.2.5 | Maneuverability | | | |
| 3.2.1.2.5.1 | Turning (dynamic) | 0.6 G lateral acceleration with less than 5 degrees roll. | Meets objective | Add "...on a dry, level hard surface." |
| | | | | |
| 3.2.1.2.5.1 | Turning (static) | 25(20) ft. curb-to-curb in less than 9.5(8) seconds | Meets 23 ft. | |
| 3.2.1.2.5.3 | Vehicle Cone Index | Maximum VCI = 22(15) | Meets 18.9 VCI | Is VCI of 15 really necessary? Refer to IPR notes. |
| 3.2.1.2.6 | Interfaces | | | |
| 3.2.1.2.6.1 | Approach Angle | At least 60(80) degrees | Meets 63 deg | |
| 3.2.1.2.6.2 | Departure Angle | At least 60(70) degrees | Meets 60 deg | |
| 3.2.1.2.6.3 | Ground Clearance | At least 15(18) inches and variable ride height | Exceeds 18 inches | Clearance adjustable from 14 inches to 18 inches at normal operating speeds. From 4 inches to 21 inches available at low operating speeds. |
| 3.2.1.2.6.4 | Break Over Angle | At least 19 degrees | Meets 19 deg | |
| 3.2.1.2.7 | Ride Quality | | | |
| 3.2.1.2.7.1 | Ride Limiting Speed | Tabulated | TBD | Same Comments as for 3.2.1.2.3.2 (Mobility Rating) above. |
| 3.2.1.2.7.2 | Obstacles | Tabulated | TBD | Same Comments as for 3.2.1.2.3.2 (Mobility Rating) above. |
| 3.2.1.2.8 | Range | 300 miles on 90% of internal fuel capacity and 450 miles with additional on board fuel reserves. | Meets objective | |

| | | | | |
|---|---|---|---|---|
| 3.2.1.2.9 | Common Components | Many | Meets all objectives | |
| 3.2.1.3 | Survivability | Many | TBD | Not addressed. |
| 3.2.1.4 | Firepower | Many | TBD | Not addressed. |
| 3.2.1.5 | C^4I | Many | TBD | Not addressed. |
| 3.2.3 | External Interfaces | Many | Meets all objectives | |
| 3.2.4 | Physical Characteristics | | | |
| 3.2.4.2 | Dimensions | Fit in V-22 aircraft | Meets objective | |
| 3.2.5 | Maintainability | Many | TBD | |
| 3.2.6 | Environmental Conditions | Many | TBD | |
| 3.2.7 | Transportability | Many | TBD | |
| 3.2.8 | Flexibility and Expansion | Many | TBD | |
| 3.2.9 | Portability | Many | TBD | |
| 3.3 | Design and Construction | Many | TBD | |
| 3.4 | Documentation | Not Applicable | | |
| 3.5 | Logistics | Many | TBD | |
| 3.6 | Personnel and Training | Many | TBD | |
| 3.7 | Characteristics of Subsystems | Many | TBD | |
| 3.8 | Precedence | Many | TBD | |



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# What's Next

**Recommendation**

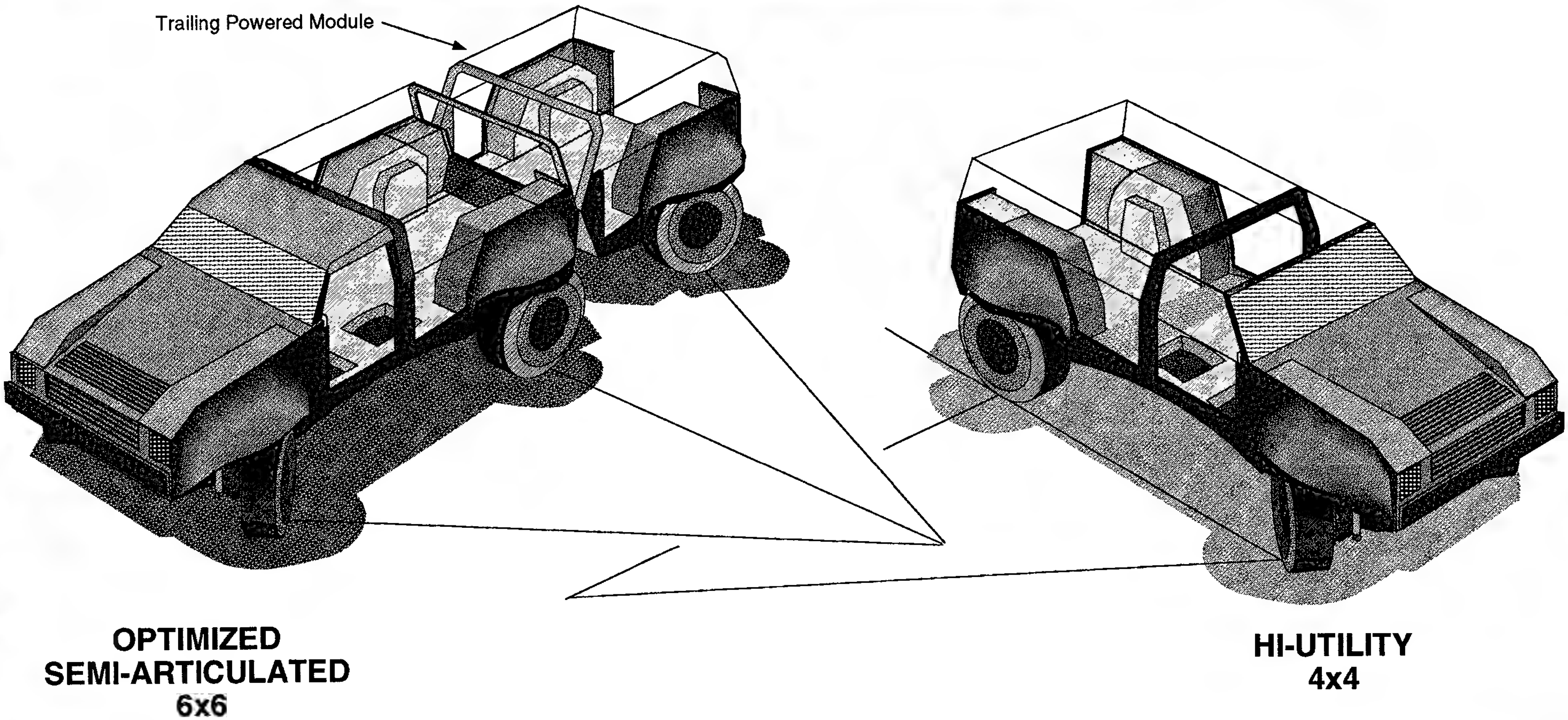
The following areas have been identified as key tasks and issues for the remainder of the study:

1. Finalize the trade decision between the 4x4 with trailer capability versus the 6x6 with articulated rear segment (trailer) based on further input from the User on payload requirements and from WES on mobility differences between the 4x4 and articulated 6x6 concepts.
2. Complete documentation of the BTA to include:
    - detailed weight study
    - CAD solid modeling
    - NRMMII data sheets/analyses
    - Examine fuel consumption reduction strategies.
3. Prepare top level payload analyses of possible variants including concept descriptions and platform burdens/interfaces.
4. Conduct risk mitigation exploration (mechanical vs. electric drive).
5. Prepare the Final Technical Report.
6. Conduct IPR #3 and IPR #4.

# 12/12 LEADING RSTV CANDIDATES
## - What's Next in Concept Study -

**MERGE CONCEPTS TO:**

- Retain utility/cost/weight benefits of 4x4 as stand-alone vehicle
- Merge volume/mobility benefits of articulated 6x6 so that trailing powered module can be exploited when needed



# APPROACH TO RST-V SHORT-TERM AND LONG-TERM PAYOFFS AT MINIMUM RISK

The payoff potential of electric drive is significant--particularly when hybrid electric technology is combined with in-wheel drive, advanced pneumatic suspensions, flexible architectures, low signature composites, high-efficiency engines, and high-utility vehicle designs.

However, to minimize program risk and maximize payoff potential, GDLS recognized that a far-term, all-or-nothing RST-V initiative would not be desirable.

Thus, a parallel goal for the RST-V study has been to develop concepts for nearer-term variants of the objective RST-V, and then to insure that the RST-V objective concept accommodates these alternatives. The three RST-V variants studied were:

1) The all-electric( hybrid), in-wheel drive RST-V baseline focus

2) An in-board electric drive variant where traction motors are in the chassis driving wheels through constant-velocity prop shafts

3) An all-mechanical drive variant in which the powertrain combines HMMWV engine and transmission with innovative drive shaft/axle/prop shaft concepts to achieve almost all the folding suspension features of the baseline despite the need for short, high-angular-travel, constant-velocity prop shafts between axle and wheel.

As a result of this investigation, the RST-V concept is being oriented to support all three possible alternatives with minimum program redirection and impact. This flexible approach will allow the RST-V initiative to:

- Be tailored as needed to support nearer-term needs
- Respond to funding constraints requiring less aggressive goals
- Adjust program direction to nearer-term solutions if key RST-V technologies do not mature adequately

The RST-V concept approach can now support aggressive goals while retaining good fall-back resilience, or it can support conservative goals while retaining inherent growth provisions to evolve into a superior solution in paced, incremental steps.

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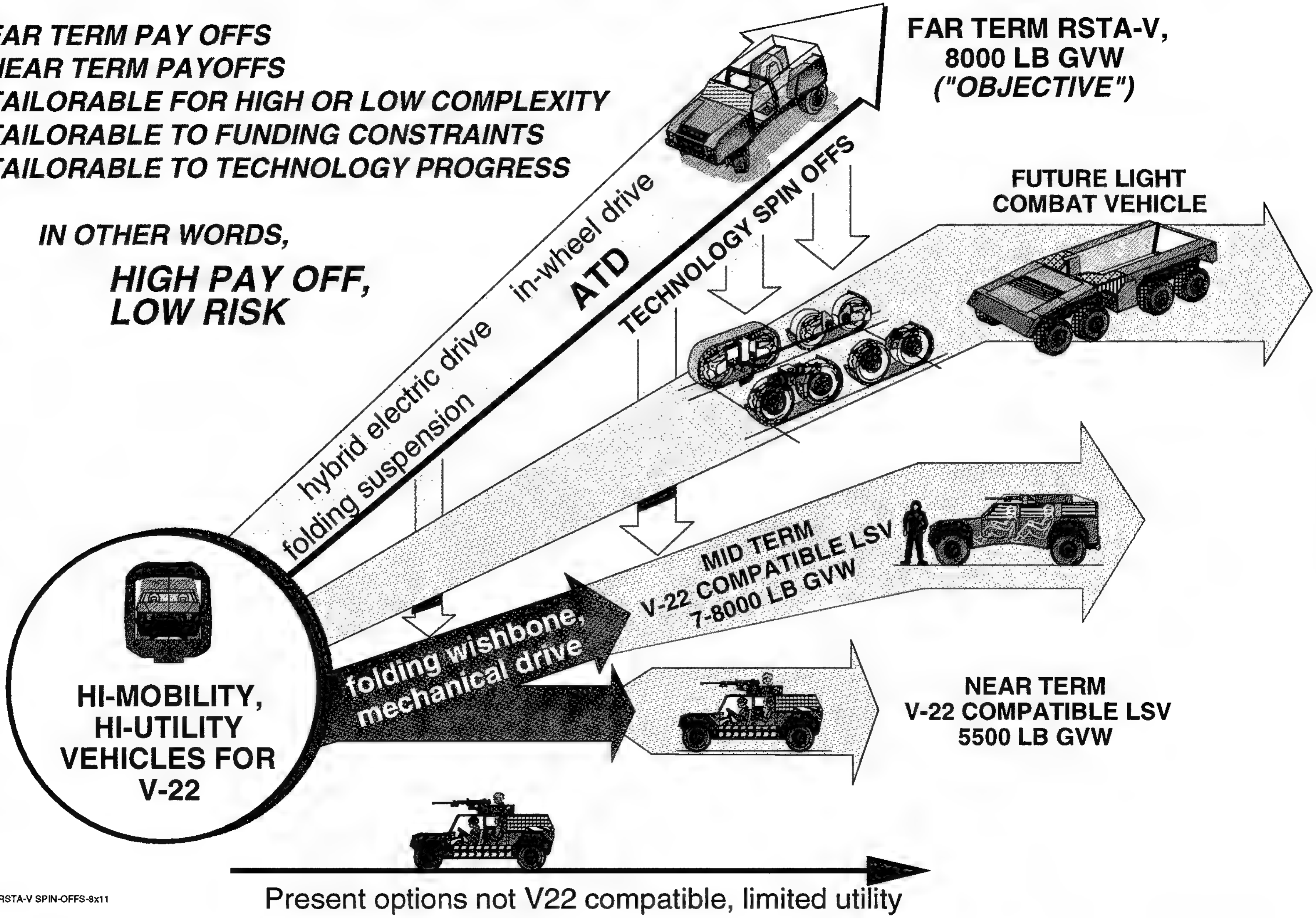
# RST-V, OBJECTIVE AND TECHNOLOGY CARRIER IN ONE

- FAR TERM PAY OFFS
- NEAR TERM PAYOFFS
- TAILORABLE FOR HIGH OR LOW COMPLEXITY
- TAILORABLE TO FUNDING CONSTRAINTS
- TAILORABLE TO TECHNOLOGY PROGRESS

IN OTHER WORDS,

**HIGH PAY OFF, LOW RISK**




RSTA-V SPIN-OFFS-8x11

# RISK-REDUCING RST-V HIGH/LOW CONCEPTS ARE WELL ALONG

***ALL-MECHANICAL SOLUTION***

The key to achieving high/low RST-V chassis design flexibility is solving the mechanical drive challenge within desired RST-V constraints. Fortunately, GDLS has been working such a problem as part of an LSV study. Thus, a design solution has been derived that provides full suspension folding capability using constant velocity prop shafts **without** exceeding their maximum allowable operating angles. Further, a unique "backward" engine/transmission layout has facilitated a very clean, low profile drive line and axle layout on the floor of the chassis and an equally-clean cooling layout. This solution is superior to any known state-of-the-art, all-mechanical drive trains available to day. Consequently, it has become the reference point for assessing benefits of E-drive.

***IN-BOARD ELECTRIC DRIVE SOLUTION***

Having solved the all-mechanical drive train problem, the in-board motor drive concept is straight forward. The prop shafts are eliminated and the axles are replaced with motor/reducer pairs driving the same wheel prop shafts developed for the all-mechanical design. Because of the front motor/axle space claim directly under the generator, the generator's shape may have to be a longer, smaller diameter cylinder like the transmission it replaces. With independent motor drive to each wheel, this hybrid electro-mechanical design can achieve almost all the same electric drive payoffs as the in-wheel electric drive--except it tends to be burdened with both electrical and mechanical complexity.

***IN-WHEEL ELECTRIC DRIVE***

Having determined how best to layout a nearly-common drive train for the all-mechanical and in-board electric drive concepts above, the baseline RST-V in-wheel drive concept can then be revisited for compatibility. In principle, the same engine/generator/power conditioning layout developed for the in-board drive can be applied to the in-wheel drive concept. In fact, more room becomes available since the motors and speed reducers are displaced from hull to wheel. This means that the in-wheel drive RST-V concept must retain easily-reclaimable space for possible in-board motors if it is to keep the in-board option open. For the mechanical drive option, the in-wheel drive concept must insure that all potential mechanical drive space claims are occupied by electrical componentry that would be removed when the electric drive was removed.

***MERGING THE THREE APPROACHES IS ALREADY PROCEEDING***

Based on the concept development work discussed above, GDLS is already developing a RST-V concept with "backward" engine/generator and other refinements to bring it into close compatibility with the all-mechanical alternative. Both concepts are being refined concurrently to provide the maximum commonality achievable without unduly compromising either concept in its own right. This work is ongoing and will be reflected in the final study results.

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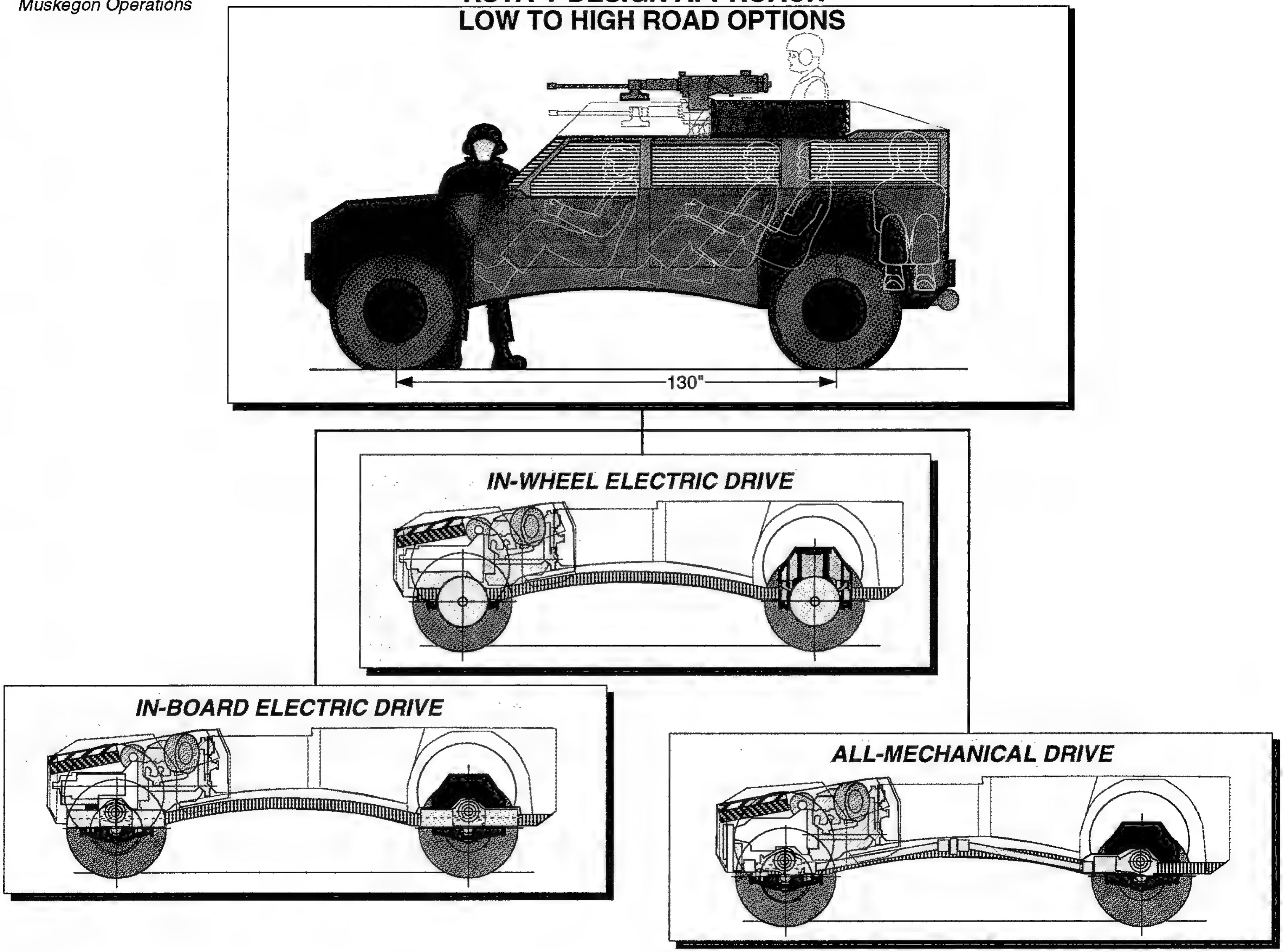
# RSTA-V DESIGN APPROACH-- LOW TO HIGH ROAD OPTIONS



# RSTA-V HIGH/LOW CONCEPTS

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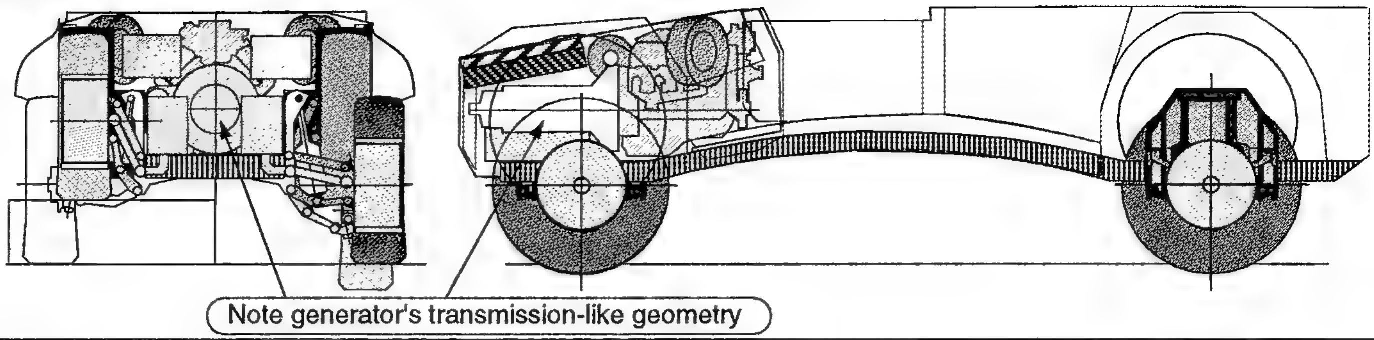
## IN-WHEEL ELECTRIC DRIVE

**Optimum high-road concept**

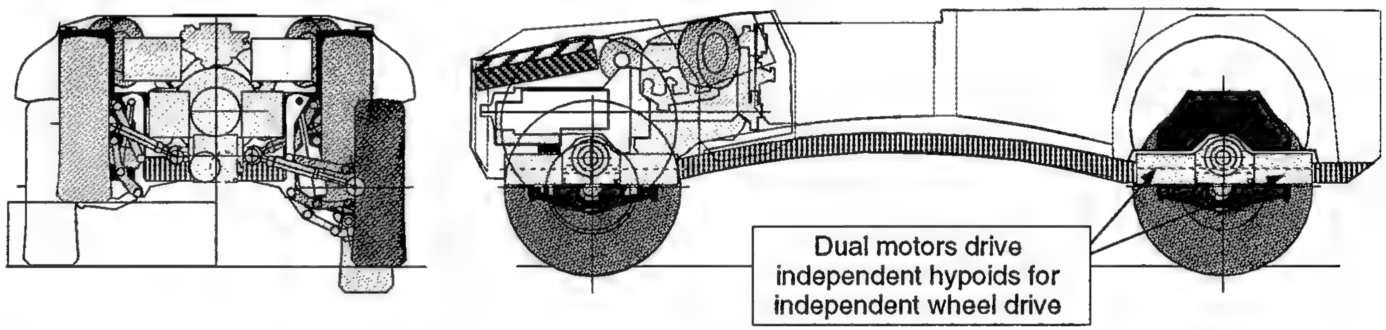
Engine, generator and cooling system configuration anticipates fall-back alternatives




## IN-CHASSIS ELECTRIC DRIVE

**Interim electric drive option**

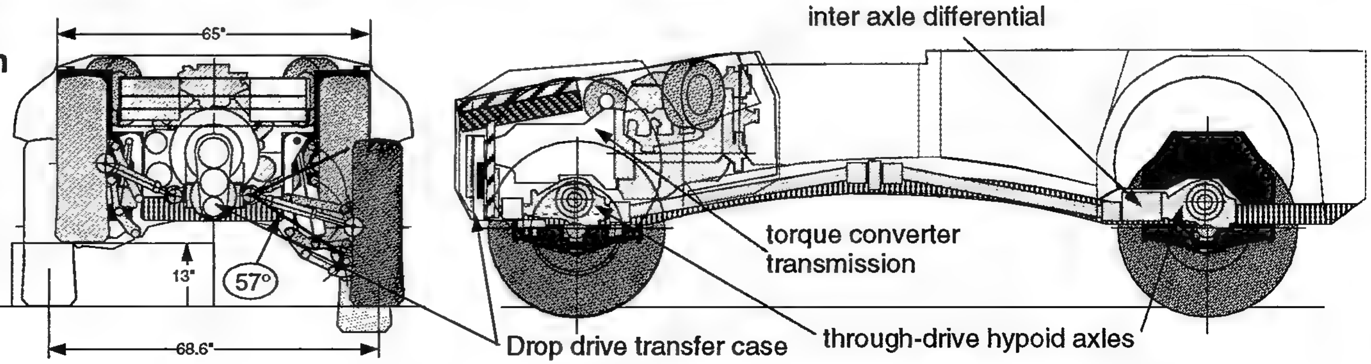
- Uses same Engine, generator and cooling system, body, frame, etc.
- Dual motor axles adopted using folding suspension with LSV-derivative prop shafts




## ALL-MECHANICAL DRIVE

**Interim Mechanical drive option**

- Uses same Engine, cooling system, body, frame, etc.
- Replaces generator with torque converter transmission and front-mounted drop drive to axles.
- Uses folding suspension with LSV-derivative prop shafts



# REVIEW OF TYPICAL FUEL CONSUMPTION SOURCES FOR HMMWV CLASS VEHICLE

HIGHWAY FUEL CONSUMPTION

Using HMMWV highway fuel consumption as a reference, an analytical breakdown of typical fuel consumption contributors has been derived. The dominant contributors for highway fuel consumption are:

- basic tire rolling resistance on hard roads--1.5%
- typcial real world grade factor--2%
- aerodynamic effects at ~50 mph
- engine BSFC contribution--a pervasive factor affecting all fuel consumption sources
- auxiliary power burdens--typical generator loads and cooling loads (assumes air cleaner/exhaust losses are already considered in the base engine BSFC and horsepower rating)
- transients reflecting added fuel burned during speed changing and start-up acceleration, maneuver losses, etc.

CROSS-COUNTRY FUEL CONSUMPTION

For cross country operation, increasing rolling resistance 4% is not a realistic indicator of real world fuel consumption. Logistics planners use a factor of 2.5xhighway fuel consumption. A good number for total rolling resistance is about 10%, which is equivalent to running in soft sand and/or running over typical rolling fields. Maintaining speed in soft sand and running on 10% grades as well can increase this number significantly, but does not represent a good average.

Cross country transient power burdens are much higher than over the road because of powering over(or through) obstacles, more exaggerated speed changes and maneuvering and a higher incidence of "pedal to the metal" accelration. (Note that a 40-50 hp/ton HMMWV is no more powerful than a 1970 Volkswagon).

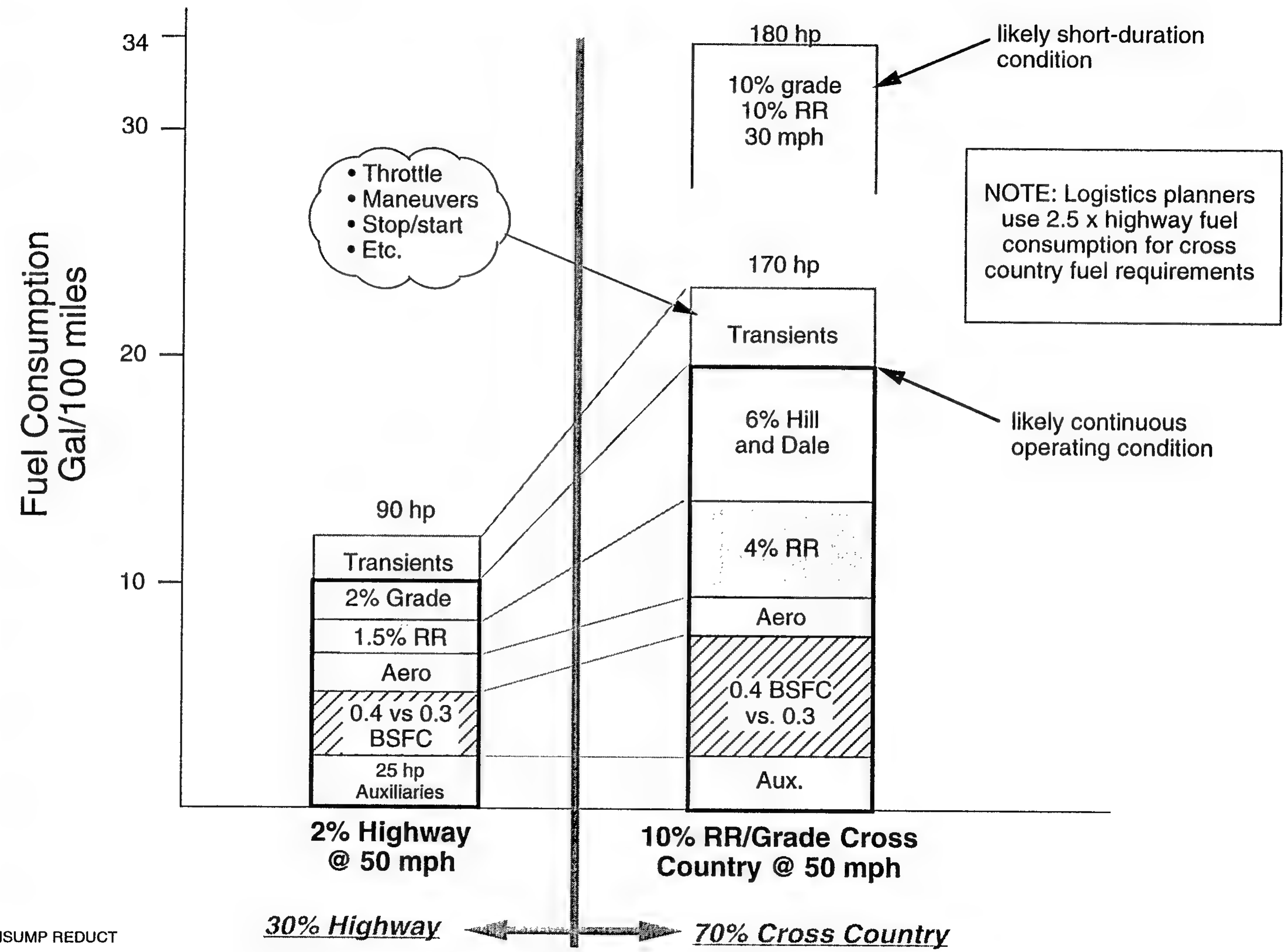
The impact of higher vs. lower BSFC is also exaggerated in cross country operation since average power is increased to maintain speed.

ANALYZING FUEL CONSUMPTION

If we are to analyze fuel consumption, particularly with the intent of making substantial reductions, the several contributors on this chart must be carefully scrutinized and agreed to by parties concerned. Also, the distribution of on vs off road operation and geographic location/seasons will have to be addressed. Agreement on rolling resistance and grades is straight forward, but deducing the contribution of transients is harder since it has received little emphasis. We will be developing preliminary numbers for this source, but it will need corroboration by the customer if addressed in any future competitive assessment.

The next Fuel Consumption viewgraph will address how E-drive can help to achieve major reductions in fuel consumption

# TYPICAL FUEL CONSUMPTION CONTRIBUTORS FOR HMMWV CLASS VEHICLE



# TECHNIQUES FOR REDUCING RSTV FUEL CONSUMPTION

A preliminary assessment of fuel consumption reduction opportunities has resulted in the following observations:

- Ultra (chemical) capacitors can be exploited to provide power(acceleration) boosts without making the engine even bigger.

- Rolling resistance losses will not change with hybrid drive, but hill and dale losses are theoretically recoverable with regenerative braking and a properly matched energy storage subsystem . This energy recovery approach is called "load leveling." Much of load leveling can be accomplished with batteries, but capacitor storage will be required as well to handle higher regeneration rates and to maximize the total percent energy recoverable. Load leveling is a key means of reducing maximum engine power requirements. A 50% reuse has been allocated in this chart.

- Transients due to changing power and acceleration demands can be recovered using ultra (chemical) capacitors, which have a higher absorption rate than batteries. This transient "load leveling" is another important means of reducing engine horsepower requirements. This chart allocates a 50% reuse effectiveness.

- Efficiency of the electric drive train is presently assumed to be no better than a good mechanical drive train. However, electric drive efficiency should prove better over the whole operating load/speed spectrum -- an important capability that will allow the engine to be operated at of near its most efficient operating point.

- Tuning tire pressure/deflection to hard roads thru soft soils can help keep rolling resistance at the lowest practical possible level.

- Reducing specific fuel consumption of the engine (fuel burned per horsepower-hour) is a major factor in vehicle fuel consumption. This reduction is best accomplished by two mutually supporting approaches :
    - exploitation of E-drive's variable output to keep the engine operating continuously at its most efficient torque/speed point
    - adoption of engines having inherently superior fuel efficiency in the first place (there is much potential beyond today's state-of-the-art engines in the form of turbo-compounding and low heat transfer techniques)

- Selection of a "fuel efficient" mode, where engine and electrical powertrain can be matched to operate near their best efficiencies, will further reduce fuel consumption. However, such optimization may also have to accommodate a high engine power mode for continuous heavy going in soft soils. This prospect of two power modes will likely become a key discriminator in electric power/motor/generator selection and in determination of maximum engine hp required vs. optimum operating point desired.

- Fully variable cooling fan drives combined with lower engine horsepower requirements will significantly reduce cooling horsepower in ambients up to 100° F. However, this improvement will be cancelled out by electrice drive cooling burdens until the thermal limits of solid state electronics reaches 210°-260° F

**The next step will be optimizing the balance of engine power, battery/capacitor storage, weight and volume for <u>all</u> expected operating capabilities. Because our electric drive architecture is modular for growth, there is time to exploit simulations followed by test verification during the ATD program to to insure that theoretical and real optimization converge.**

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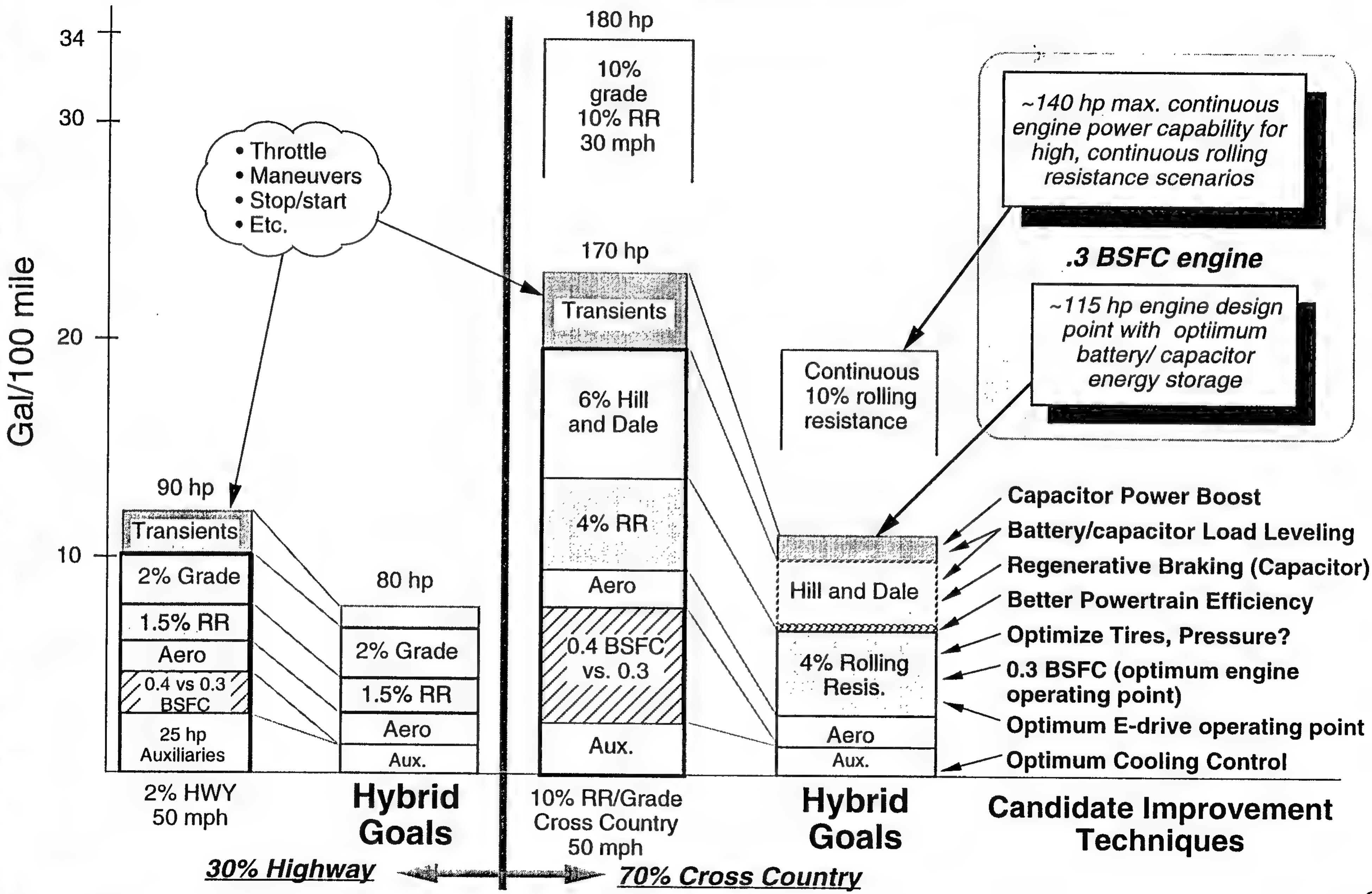
# REDUCING RSTV FUEL CONSUMPTION WITH E-DRIVE
## (A System Problem)



# Appendix 1 - Weight Data Sheets

# RSTV 4x4 Weight Table

| WBS # | Title | Description | Sets | Item Wgt | Set Wgt | Subsystem | Vehicle | Rationale |
|---|---|---|---|---|---|---|---|---|
| 1.0 | **Vehicle** | | | | | | 5163 | |
| **1.01** | **Integration & Assembly** | Paint, POL, Misc | 1 | | 0 | 0 | | HMMWV |
| **1.02** | **Hull** | | | | | 1085 | | |
| 1.02.01 | Basic Hull | Frame Ass'y | 1 | 600 | 600 | | | 1.5 (GVW) x HTMMP Space Frame 400 lb |
| 1.02.02 | Hull Bolts & Misc. | Included in Hull | 0 | 0 | 0 | | | |
| 1.02.03 | Bulkhead, Grilles & Covers | Cab/Body Panels | 1 | 281 | 281 | | | 1.1 (LENGTH) x HTMMP body 255 lbs |
| 1.02.04 | Accommondations | Seats | 4 | 20 | 80 | | | HTMMP Seat Weight |
| 1.02.05 | Cargo Tie Downs/Restraints | Included in frame | 0 | 0 | 0 | | | |
| 1.02.06 | Appendages | Bumpers & Pintle | 2 | 62 | 124 | | | 0.5 x HMMWV bumper 124 lbs |
| 1.02.07 | Ingress/Egress Systems | Included in Cab | 0 | 0 | 0 | | | |
| 1.02.08 | Applique Armor | na | 0 | 0 | 0 | | | |
| 1.02.09 | Hull I&A | na | 0 | 0 | 0 | | | |
| **1.03** | **Suspension & Steering** | | | | | 1041 | | |
| 1.03.01 | Springing System | Springs | 4 | 18 | 72 | | | Engineering estimate |
| 1.03.02 | Damping System | Shocks | 4 | 9 | 36 | | | Engineering estimate |
| 1.03.03 | Roadwheel Ass'y | | | | | | | |
| | | Wheel | 4 | 36 | 144 | | | 2 x HTMMP (18 lbs) |
| | | Tire | 4 | 94 | 376 | | | Goodyear estimate |
| | | RunFlat | 4 | 24 | 96 | | | Hutchinson composite runflat |
| 1.03.04 | Other | | | | | | | |
| | | Knuckle/Spindle | 4 | 48 | 192 | | | Engineering estimate |
| | | Road Arms | 4 | 18 | 72 | | | Engineering estimate |
| | | Steering | 1 | 49 | 49 | | | Engineering estimate |
| | | Tie Rod | 2 | 2 | 4 | | | Engineering estimate |
| 1.03.05 | I&A | | 0 | 0 | 0 | | | |
| **1.04** | **Engine** | | | | | 1184 | | |
| 1.04.01 | Primary Engine | Engine - starter/gen. | 1 | 728 | 728 | | | HMMWV data (687 lbs dry) |
| 1.04.02 | Engine Electrical | | 1 | 13 | 13 | | | HMMWV data ? |
| 1.04.03 | Induction/Exhaust | | 1 | 83 | 83 | | | HMMWV data |
| 1.04.04 | Automotive Cooling | | 1 | 145 | 145 | | | HMMWV data |
| 1.04.05 | Fuel System | | 1 | 215 | 215 | | | HMMWV data x .85 |
| 1.04.06 | Power Take-Off | | 0 | 0 | 0 | | | |
| 1.04.07 | Engine I&A | | 0 | 0 | 0 | | | |
| **1.05** | **Automotive Drive Train** | | | | | 971 | | |
| 1.05.01 | Transmission | na | 0 | 0 | 0 | | | |
| 1.05.02 | Transfer Case | Motors, GB, power e | 4 | 189 | 756 | | | Magnetic Motors estimate |
| 1.05.03 | Shafting & Assoc. Hdwe | Harnesses, lines | 1 | 49 | 49 | | | Magnetic Motors estimate |
| 1.05.04 | Final Drives | na | 0 | 0 | 0 | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1.05.05 | Brake System | Mechanical | 4 | 21 | 82 | | | Eng. est. |
| 1.05.06 | I&A | Brake elec. & grid | 1 | 84 | 84 | | | Magnetic Motors estimate |
| **1.06** | **Not Used** | | | | | 0 | | |
| **1.07** | **Auxiliary Systems** | | | | | 548 | | |
| 1.07.01 | Electrical System | Harness, fuse box | 1 | 17 | 17 | | | |
| 1.07.01.01 | Alternator/Generator | Gen./Starter & Elect. | 1 | 125 | 125 | | | Magnetic Motors estimate |
| 1.07.01.02 | Electric Motors | na | 0 | 0 | 0 | | | |
| 1.07.01.03 | Cabling | na | 0 | 0 | 0 | | | |
| 1.07.01.04 | Batteries | | 2 | 71 | 142 | | | 2 mil lead acid batteries |
| 1.07.01.05 | Capacitors | Ultra-caps | 140 | 1 | 185 | | | Maxwell brochure |
| 1.07.01.06 | Lighting | | 1 | 8 | 8 | | | |
| 1.07.01.07 | Other | HVAC | 1 | 21 | 21 | | | |
| 1.07.01.07 | I&A | Pneumatics | 1 | 50 | 50 | | | |
| 1.07.02 | Hydrualic System | NA | 0 | 0 | 0 | | | |
| 1.07.03 | Environmental System | NA | 0 | 0 | 0 | | | |
| 1.07.04 | NBC Suite | NA | 0 | 0 | 0 | | | |
| 1.07.05 | Fire Detection & Suppression | NA | 1 | 0 | 0 | | | |
| 1.07.06 | Night Vision Device(s) | NA | 0 | 0 | 0 | | | |
| 1.07.07 | Bilge Pump | NA | 0 | 0 | 0 | | | |
| 1.07.08 | Collateral Equipment | NA | 0 | 0 | 0 | | | |
| 1.07.09 | APU | NA | 0 | 0 | 0 | | | |
| 1.07.10 | Diagnostics Equipment | NA | 0 | 0 | 0 | | | |
| **1.08** | **Turret Assembly** | Payload | 0 | 0 | 0 | | | |
| **1.09** | **Fire Control** | Payload | 0 | 0 | 0 | | | |
| **1.10** | **Armament** | Payload | 0 | 0 | 0 | | | |
| **1.11** | **Special Eqiupment** | Payload | 0 | 0 | 0 | | | |
| **1.12** | **COM/NAV** | Payload | 0 | 0 | 0 | | | |
| **1.13** | **Not Used** | Payload | 0 | 0 | 0 | | | |
| **1.14** | **Controls & Displays** | Payload | 0 | 0 | 0 | | | |
| **1.15** | **Software** | Payload | 0 | 0 | 0 | | | |
| **1.16** | **OBE** | | | | | 335 | | |



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## RSTV 6x6 Weight Table

| WBS # | Title | Description | Sets | Item Wgt | Set Wgt | Subsystem | Vehicle | Rationale |
|---|---|---|---|---|---|---|---|---|
| 1.0 | **Vehicle** | | | | | | 5558 | |
| 1.01 | **Integration & Assembly** | Paint, POL, Misc | 1 | 0 | 0 | 0 | | HMMWV |
| 1.02 | **Hull** | | | | | 1085 | | |
| 1.02.01 | Basic Hull | Frame Ass'y | 1 | 600 | 600 | | | 1.55 x HTMMP Space Frame 400 lbs |
| 1.02.02 | Hull Bolts & Misc. | Included in Hull | 0 | 0 | 0 | | | |
| 1.02.03 | Bulkhead, Grilles & Covers | Body Panels/wind sl | 1 | 281 | 281 | | | 1.35 x HTMMP body 255 lbs |
| 1.02.04 | Accommondations | Seats | 4 | 20 | 80 | | | HTMMP Seat Weight |
| 1.02.05 | Cargo Tie Downs/Restraints | Included in frame | 0 | 0 | 0 | | | |
| 1.02.06 | Appendages | Bumpers & Pintle | 2 | 62 | 124 | | | 0.5 x HMMWV bumper 124 lbs |
| 1.02.07 | Ingress/Egress Systems | Included in Cab | 0 | 0 | 0 | | | |
| 1.02.08 | Applique Armor | na | 0 | 0 | 0 | | | |
| 1.02.09 | Hull I&A | na | 0 | 0 | 0 | | | |
| 1.03 | **Suspension & Steering** | | | | | 1242 | | |
| 1.03.01 | Springing System | Springs | 6 | 18 | 108 | | | Engineering estimate |
| 1.03.02 | Damping System | Shocks | 6 | 9 | 54 | | | Engineering estimate |
| 1.03.03 | Roadwheel Ass'y | | | | | | | |
| | | Wheel | 6 | 30 | 180 | | | 2 x HTMMP |
| | | Tire | 6 | 60 | 360 | | | Goodyear estimate |
| | | RunFlat | 6 | 15 | 90 | | | Hutchinson composite runflat |
| 1.03.04 | Other | | | | | | | |
| | | Knuckle/Spindle | 6 | 48 | 288 | | | Engineering estimate |
| | | Road Arms | 6 | 18 | 108 | | | Engineering estimate |
| | | Steering | 1 | 50 | 50 | | | Engineering estimate |
| | | Tie Rod | 2 | 2 | 4 | | | Engineering estimate |
| 1.03.05 | I&A | | 0 | 0 | 0 | | | |
| 1.04 | **Engine** | | | | | 1184 | | |
| 1.04.01 | Primary Engine | | 1 | 728 | 728 | | | Rotary |
| 1.04.02 | Engine Electrical | | 1 | 13 | 13 | | | HMMWV data - gen & starter |
| 1.04.03 | Induction/Exhaust | | 1 | 83 | 83 | | | HMMWV data |
| 1.04.04 | Automotive Cooling | | 1 | 145 | 145 | | | HMMWV data |
| 1.04.05 | Fuel System | | 1 | 215 | 215 | | | HMMWV data x .85 |
| 1.04.06 | Power Take-Off | | 0 | 0 | 0 | | | |
| 1.04.07 | Engine I&A | | 0 | 0 | 0 | | | |
| 1.05 | **Automotive Drive Train** | | | | | 1165 | | |
| 1.05.01 | Transmission | na | 0 | 0 | 0 | | | |
| 1.05.02 | Transfer Case | Motors, GB, power e | 6 | 150 | 900 | | | Magnetic Motors estimate |
| 1.05.03 | Shafting & Assoc. Hdwe | Harnesses, lines | 1 | 61 | 61 | | | Magnetic Motors estimate |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1.05.04 | Final Drives | na | 0 | 0 | 0 | | | |
| 1.05.05 | Brake System | Mechanical | 6 | 20 | 120 | | | Eng. est. |
| 1.05.06 | I&A | Brake elec. & grid | 1 | 84 | 84 | | | Magnetic Motors estimate |
| **1.06** | **Not Used** | | | | | 0 | | |
| **1.07** | **Auxiliary Systems** | | | | | 548 | | |
| 1.07.01 | Electrical System | Harness, fuse box | 1 | 17 | 17 | | | |
| 1.07.01.01 | Alternator/Generator | Gen./Starter & Elect | 1 | 125 | 125 | | | Magnetic Motors estimate |
| 1.07.01.02 | Electric Motors | na | 0 | 0 | 0 | | | |
| 1.07.01.03 | Cabling | na | 0 | 0 | 0 | | | |
| 1.07.01.04 | Batteries | | 2 | 71 | 142 | | | 2 mil lead acid batteries |
| 1.07.01.05 | Capacitors | Ultra-caps | 140 | 1 | 185 | | | Maxwell brochure |
| 1.07.01.06 | Lighting | | 1 | 8 | 8 | | | |
| 1.07.01.07 | Other | HVAC | 1 | 21 | 21 | | | |
| 1.07.01.07 | I&A | Pneumatics | 1 | 50 | 50 | | | Questimate! |
| 1.07.02 | Hydrualic System | NA | 0 | 0 | 0 | | | |
| 1.07.03 | Environmental System | NA | 0 | 0 | 0 | | | |
| 1.07.04 | NBC Suite | NA | 0 | 0 | 0 | | | |
| 1.07.05 | Fire Detection & Suppression | | 1 | 0 | 0 | | | |
| 1.07.06 | Night Vision Device(s) | | 0 | 0 | 0 | | | |
| 1.07.07 | Bilge Pump | NA | 0 | 0 | 0 | | | |
| 1.07.08 | Collateral Equipment | | 0 | 0 | 0 | | | |
| 1.07.09 | APU | NA | 0 | 0 | 0 | | | |
| 1.07.10 | Diagnostics Equipment | | 0 | 0 | 0 | | | |
| **1.08** | **Turret Assembly** | | 0 | 0 | 0 | | | |
| **1.09** | **Fire Control** | | 0 | 0 | 0 | | | |
| **1.10** | **Armament** | | 0 | 0 | 0 | | | |
| **1.11** | **Special Eqiupment** | | 0 | 0 | 0 | | | |
| **1.12** | **COM/NAV** | | 0 | 0 | 0 | | | |
| **1.13** | **Not Used** | NA | 0 | 0 | 0 | | | |
| **1.14** | **Controls & Displays** | | 0 | 0 | 0 | | | |
| **1.15** | **Software** | NA | 0 | 0 | 0 | | | |
| **1.16** | **OBE** | | | | | 335 | | |



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# RSTV Tracked Weight Table

| WBS # | Title | Description | Sets | Item Wgt | Set Wgt | Subsystem | Vehicle | Rationale |
|---|---|---|---|---|---|---|---|---|
| 1.0 | **Vehicle** | | | | | | 6394 | |
| **1.01** | **Integration & Assembly** | Paint, POL, Misc | 1 | 0 | 0 | 0 | | HMMWV |
| **1.02** | **Hull** | | | | | 1085 | | |
| 1.02.01 | Basic Hull | Frame Ass'y | 1 | 600 | 600 | | | 1.50 x HTMMP Space Frame 400 lbs |
| 1.02.02 | Hull Bolts & Misc. | Included in Hull | 0 | 0 | 0 | | | |
| 1.02.03 | Bulkhead, Grilles & Covers | Body Panels/wind sh | 1 | 281 | 281 | | | 1.1 x HTMMP body 255 lbs |
| 1.02.04 | Accommondations | Seats | 4 | 20 | 80 | | | HTMMP Seat Weight |
| 1.02.05 | Cargo Tie Downs/Restraints | Included in frame | 0 | 0 | 0 | | | |
| 1.02.06 | Appendages | Bumpers & Pintle | 2 | 62 | 124 | | | 0.5 x HMMWV bumper 124 lbs |
| 1.02.07 | Ingress/Egress Systems | Included in Cab | 0 | 0 | 0 | | | |
| 1.02.08 | Applique Armor | na | 0 | 0 | 0 | | | |
| 1.02.09 | Hull I&A | na | 0 | 0 | 0 | | | |
| **1.03** | **Suspension & Steering** | | | | | 2258 | | |
| 1.03.01 | Springing System | Springs | 8 | 18 | 144 | | | Engineering estimate |
| 1.03.02 | Damping System | Shocks | 8 | 9 | 72 | | | Engineering estimate |
| 1.03.03 | Roadwheel Ass'y | | | | | | | |
| | | Wheel | 8 | 30 | 240 | | | Engineering Estimate |
| | | Tire/sprocket | 4 | 55 | 220 | | | Engineering Estimate |
| | | RunFlat/track | 2 | 449 | 898 | | | Goodyear Estimate |
| 1.03.04 | Other | | | | | | | |
| | | Knuckle/Spindle | 8 | 48 | 384 | | | Engineering estimate |
| | | Road Arms | 8 | 18 | 144 | | | Engineering estimate |
| | | Tension Arms | 2 | 78 | 156 | | | Engineering estimate |
| | | Tie Rod | 0 | 2 | 0 | | | Engineering estimate |
| 1.03.05 | I&A | | 0 | 0 | 0 | | | |
| **1.04** | **Engine** | | | | | 1184 | | |
| 1.04.01 | Primary Engine | | 1 | 728 | 728 | | | Diesel |
| 1.04.02 | Engine Electrical | | 1 | 13 | 13 | | | HMMWV data - gen & starter |
| 1.04.03 | Induction/Exhaust | | 1 | 83 | 83 | | | HMMWV data |
| 1.04.04 | Automotive Cooling | | 1 | 145 | 145 | | | HMMWV data |
| 1.04.05 | Fuel System | | 1 | 215 | 215 | | | HMMWV data x .85 |
| 1.04.06 | Power Take-Off | | 0 | 0 | 0 | | | |
| 1.04.07 | Engine I&A | | 0 | 0 | 0 | | | |
| **1.05** | **Automotive Drive Train** | | | | | 985 | | |
| 1.05.01 | Transmission | na | 0 | 0 | 0 | | | |
| 1.05.02 | Transfer Case | Motors, GB, power e | 4 | 189 | 756 | | | Magnetic Motors estimate |
| 1.05.03 | Shafting & Assoc. Hdwe | Harnesses, lines | 1 | 49 | 49 | | | Magnetic Motors estimate |



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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1.05.04 | Final Drives | na | 0 | 0 | 0 | | | |
| 1.05.05 | Brake System | Mechanical | 4 | 24 | 96 | | | Eng. est. |
| 1.05.06 | I&A | Brake elec. & grid | 1 | 84 | 84 | | | Magnetic Motors estimate |
| **1.06** | **Not Used** | | | | | 0 | | |
| **1.07** | **Auxiliary Systems** | | | | | 548 | | |
| 1.07.01 | Electrical System | Harness, fuse box | 1 | 17 | 17 | | | |
| 1.07.01.01 | Alternator/Generator | Gen./Starter & Elect | 1 | 125 | 125 | | | Magnetic Motors estimate |
| 1.07.01.02 | Electric Motors | na | 0 | 0 | 0 | | | |
| 1.07.01.03 | Cabling | na | 0 | 0 | 0 | | | |
| 1.07.01.04 | Batteries | | 2 | 71 | 142 | | | 2 mil lead acid batteries |
| 1.07.01.05 | Capacitors | Ultra-caps | 140 | 1 | 185 | | | Maxwell brochure |
| 1.07.01.06 | Lighting | | 1 | 8 | 8 | | | |
| 1.07.01.07 | Other | HVAC | 1 | 21 | 21 | | | |
| 1.07.01.07 | I&A | Pneumatics | 1 | 50 | 50 | | | Questimate! |
| 1.07.02 | Hydrualic System | NA | 0 | 0 | 0 | | | |
| 1.07.03 | Environmental System | NA | 0 | 0 | 0 | | | |
| 1.07.04 | NBC Suite | NA | 0 | 0 | 0 | | | |
| 1.07.05 | Fire Detection & Suppression | | 1 | 0 | 0 | | | |
| 1.07.06 | Night Vision Device(s) | | 0 | 0 | 0 | | | |
| 1.07.07 | Bilge Pump | NA | 0 | 0 | 0 | | | |
| 1.07.08 | Collateral Equipment | | 0 | 0 | 0 | | | |
| 1.07.09 | APU | NA | 0 | 0 | 0 | | | |
| 1.07.10 | Diagnostics Equipment | | 0 | 0 | 0 | | | |
| **1.08** | **Turret Assembly** | | 0 | 0 | 0 | | | |
| **1.09** | **Fire Control** | | 0 | 0 | 0 | | | |
| **1.10** | **Armament** | | 0 | 0 | 0 | | | |
| **1.11** | **Special Eqiupment** | | 0 | 0 | 0 | | | |
| **1.12** | **COM/NAV** | | 0 | 0 | 0 | | | |
| **1.13** | **Not Used** | NA | 0 | 0 | 0 | | | |
| **1.14** | **Controls & Displays** | | 0 | 0 | 0 | | | |
| **1.15** | **Software** | NA | 0 | 0 | 0 | | | |
| **1.16** | **OBE** | | | | | 335 | | |



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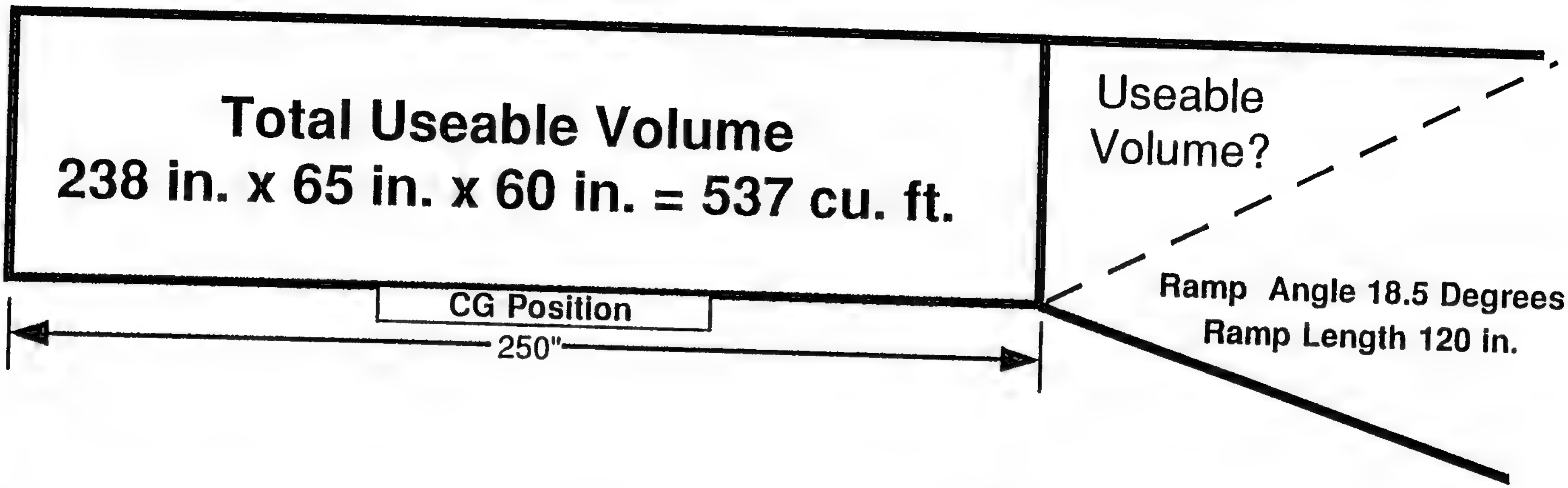
# Appendix 2 - Volume Data Sheets

GENERAL DYNAMICS
Land Systems
Muskegon Operations

For Government Use Only

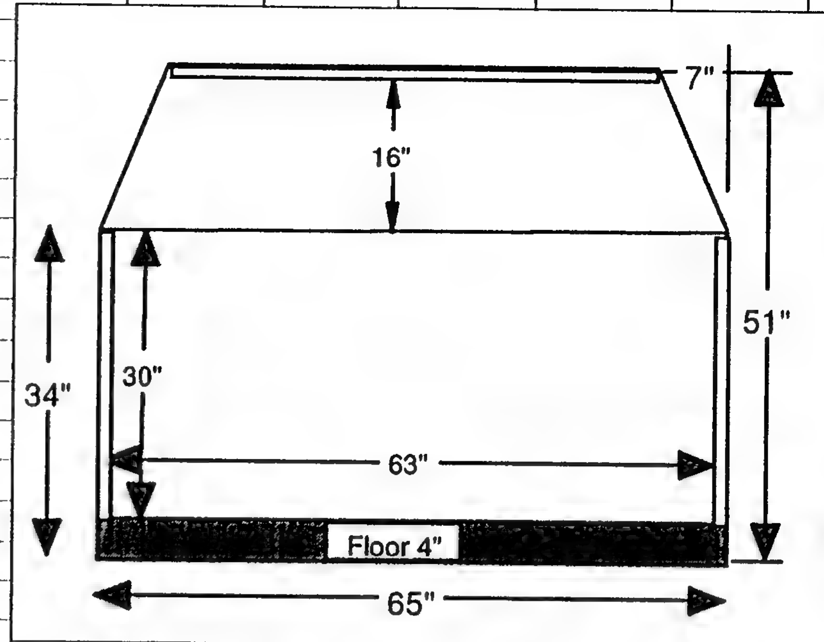
# V-22 Transportation Considerations




- MIL-STD-1366C, Crash Load Restraint Criteria - 16 g's fwd/down, 10 g's lateral, 5 g's up/aft.
- Width Criteria - 68 in. minus at least 1.5 inches clearance sides and top.
- Tie down clearances - TBD inches from vehicle to avionics rack and ramp.
- Safety - access (crew space from rear of aircraft (ramp) to forward section.
- Tiedown strapping - Vehicle OVE.
- Vehicle ramp breakover angle - 18.5 degrees.

# Payload Volume Computations
## 4x4 Concept

| | |
|---|---|
| **Hull** | |
| **Section Area** | |
| Lower Section | 1890 |
| Upper Section | 896 |
| Total (Sq. In.) | 2786 |
| Total (Sq Ft) | 19.3 |
| | |
| **Gross Volume** | |
| Ave Length (ft) | 10.8 |
| Total Volume cu. ft. | 209.6 |
| | |
| **Suspension** | |
| **Wheel Well Volume** | |
| 23.5 in. Radius | 867 |
| 6in. x 47 in. lower | 276 |
| Total Area | 1143 |
| Width | 11.5 |
| Total volume | 13145 |
| Total volume | 7.6 |
| | |
| **Strut Tower** | |
| Height | 24 |
| Width | 18 |
| Thickness | 6 |
| Total Volume (cu. in.) | 2592 |
| Total Volume (sq.in.) | 1.5 |
| | |
| **Total Suspension** | 9.1 |



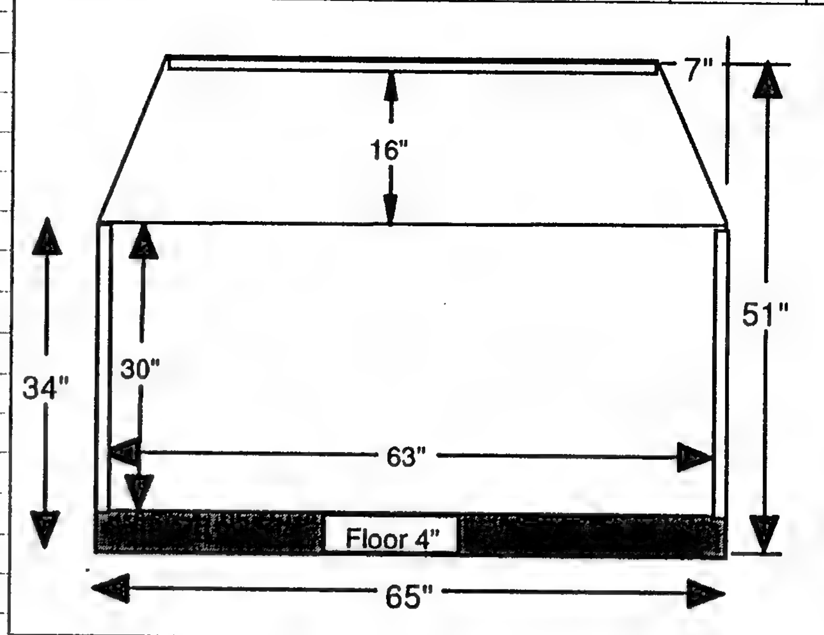

Assumptions: 5 in. thick floor, 1/2 in. thick roof and side walls.
Vehicle height limited to 51 in. transport configuration.
V-22 clearance: 1.5 in. per side, 4 in. floor clearance.

| | |
|---|---|
| **Battery/Console** | |
| Height | 12 |
| Width | 22 |
| Length | 34 |
| Total Volume (cu. in.) | 8976 |
| Total Volume (cu. ft.) | 5.2 |

| | |
|---|---|
| **Useable Volume** | |
| Gross | 209.6 |
| - 2x Susp | 18.2 |
| - battery/console | 5.2 |
| | |
| Total (cu. ft.) | 186.2 |

## Payload Volume Computations
## 6x6 Concept

| | |
|---|---|
| **Hull** | |
| **Section Area** | |
| Lower Section | 1890 |
| Upper Section | 896 |
| Total (Sq. In.) | 2786 |
| Total (Sq Ft) | 19.3 |
| | |
| **Gross Volume** | |
| Ave Length (ft) | 10.8 |
| Total Volume cu. ft. | 209.6 |
| | |
| **Suspension - Walking Beam** | |
| **Wheel Well Volume** | |
| 83 in length | 83 |
| 30 in. height | 30 |
| Total Area | 2321 |
| Width | 10.5 |
| Total volume | 24371 |
| Total volume | 14.1 |
| | |
| **Strut Tower** | |
| Height | 24 |
| Width | 18 |
| Thickness | 6 |
| Total Volume (cu. in.) | 2592 |
| Total Volume (sq.in.) | 1.5 |
| | |
| **Total Suspension** | 15.6 |



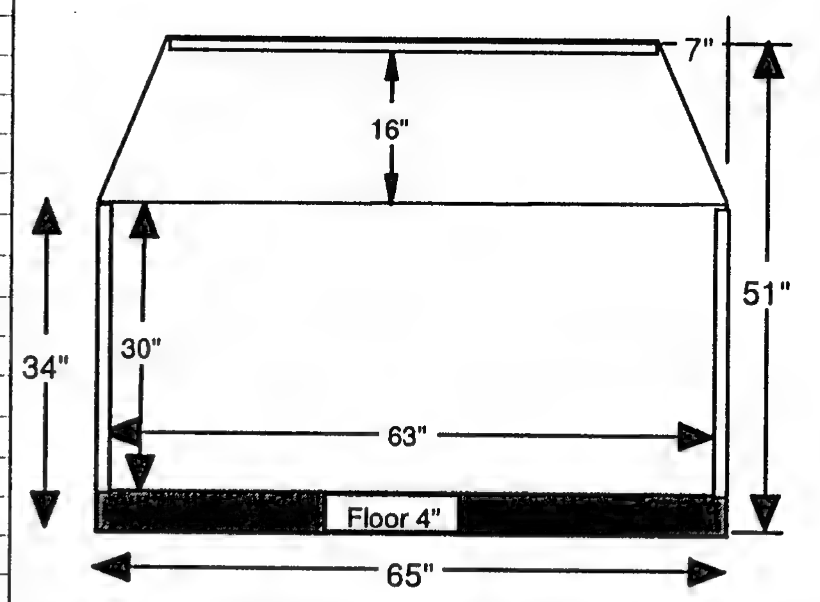

Assumptions: 5 in. thick floor, 1/2 in. thick roof and side walls.
Vehicle height limited to 51 in. transport configuration.
V-22 clearance: 1.5 in. per side, 4 in. floor clearance.
10 in. top clearance includes armament.

| | |
|---|---|
| **Battery/Console** | |
| Height | 12 |
| Width | 22 |
| Length | 34 |
| Total Volume (cu. in.) | 8976 |
| Total Volume (cu. ft.) | 5.2 |

| | |
|---|---|
| **Useable Volume** | |
| Gross | 209.6 |
| - 2x Susp | 31.2 |
| - battery/console | 5.2 |
| | |
| Total (cu. ft.) | 173.2 |

# Payload Volume Computations
## 6x6a Concept

| | | | |
|---|---|---|---|
| **Hull** | | | |
| **Section Area** | Front | Rear | |
| Lower Section | 1890 | 1890 | |
| Upper Section | 896 | 896 | |
| Total (Sq. In.) | 2786 | 2786 | |
| Total (Sq Ft) | 19.3 | 19.3 | |
| | | | |
| **Gross Volume** | | | |
| Ave Length (ft) | 9 | 5.7 | |
| Total Volume cu. ft. | 174.1 | 109.6 | 283.8 |
| | | | |
| **Suspension** | | | |
| **Wheel Well Volume** | | | |
| 21 in. Radius | 692 | | |
| 5 in. x 42 in. lower | 210 | | |
| Total Area | 902 | | |
| Width | 10.5 | | |
| Total volume | 9474.9 | | |
| Total volume | 5.5 | | |
| | | | |
| **Strut Tower** | | | |
| Height | 24 | | |
| Width | 18 | | |
| Thickness | 6 | | |
| Total Volume (cu. in.) | 2592 | | |
| Total Volume (sq.in.) | 1.5 | | |
| | | | |
| **Total Suspension (cu. ft.)** | 7.0 | | |



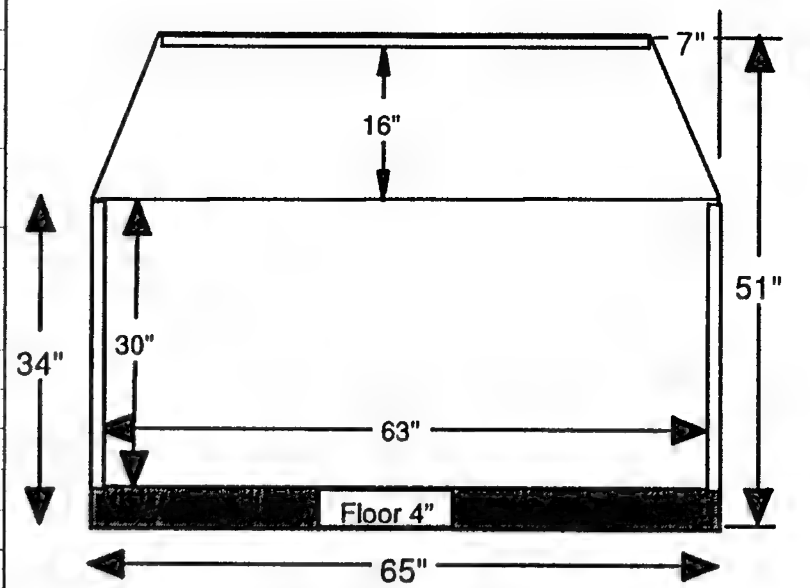

Assumptions: 5 in. thick floor, 1/2 in. thick roof and side walls.
Vehicle height limited to 51 in. transport configuration.
V-22 clearance: 1.5 in. per side, 4 in. floor clearance.

| | |
|---|---|
| **Battery/Console** | |
| Height | 12 |
| Width | 22 |
| Length | 34 |
| Total Volume (cu. in.) | 8976 |
| Total Volume (cu. ft.) | 5.2 |

| | |
|---|---|
| **Useable Volume** | |
| Gross | 283.8 |
| - 4x Susp | 27.9 |
| - battery/console | 5.2 |
| | |
| Total (cu. ft.) | 250.6 |

# Payload Volume Computations
## Tracked Concept

| | |
|---|---|
| **Hull** | |
| **Section Area** | |
| Lower Section | 1890 |
| Upper Section | 896 |
| Total (Sq. In.) | 2786 |
| Total (Sq Ft) | 19.3 |
| | |
| **Gross Volume** | |
| Ave Length (ft) | 10.8 |
| Total Volume cu. ft. | 209.6 |
| | |
| **Suspension** | |
| **Track Volume** | |
| Height | 27 |
| Length | 130 |
| width | 12 |
| Volume (cu. in.) | 42,120 |
| Volume (cu. ft.) | 24.4 |
| Total volume x 2 | 48.8 |
| | |
| **Total Suspension** | 48.8 |

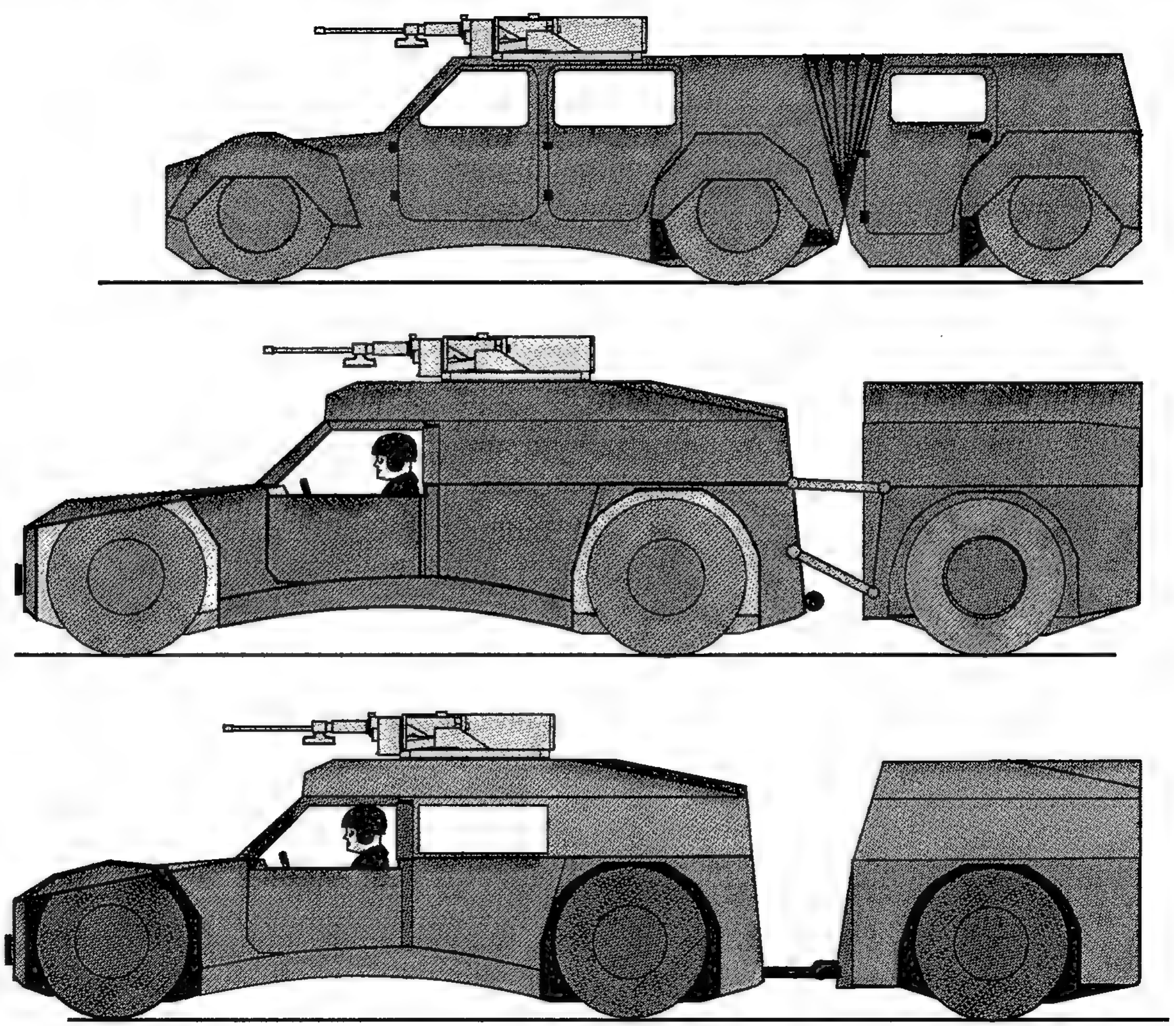



Assumptions: 5 in. thick floor, 1/2 in. thick roof and side walls.
Vehicle height limited to 51 in. transport configuration.
V-22 clearance: 1.5 in. per side, 4 in. floor clearance.
10 in. top clearance includes armament.

| **Battery/Console** | |
|---|---|
| Height | 12 |
| Width | 22 |
| Length | 34 |
| Total Volume (cu. in.) | 8976 |
| Total Volume (cu. ft.) | 5.2 |

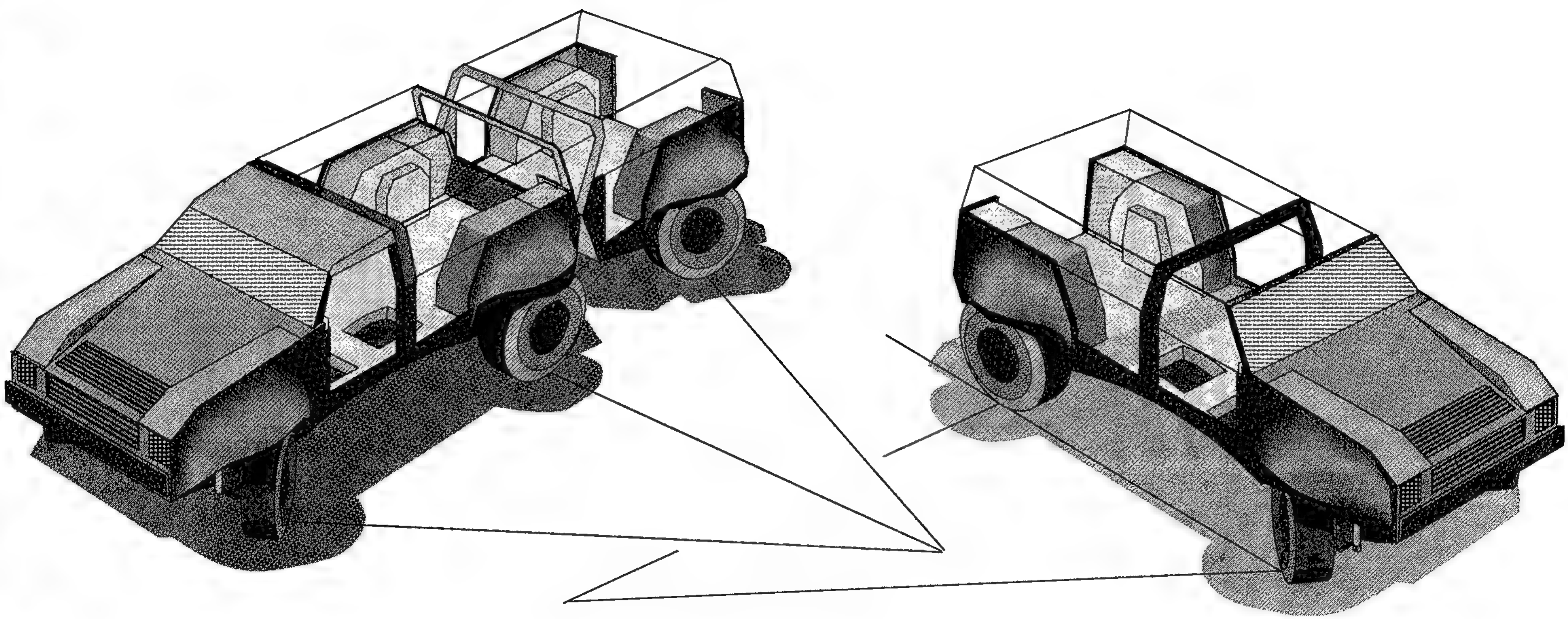
| **Useable Volume** | |
|---|---|
| Gross | 209.6 |
| - Susp | 48.8 |
| - battery/console | 5.2 |
| | |
| Total (cu. ft.) | 155.7 |

# RSTV WITH TRAILER OR ARTICULATED?



DEPENDS ON THE DEGREE OF INTEGRATION

# 12/8 LEADING RSTV CANDIDATES



**GENERAL DYNAMICS**
Land Systems
Muskegon Operations

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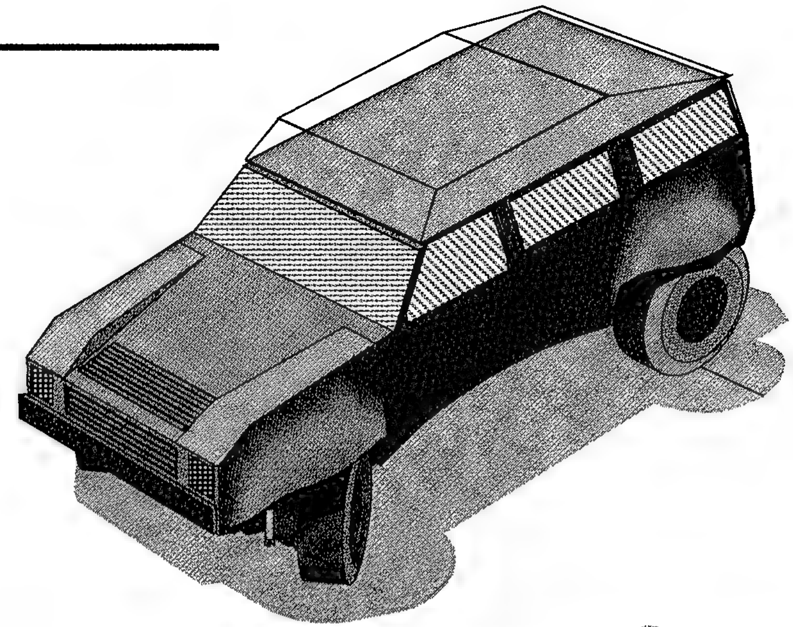
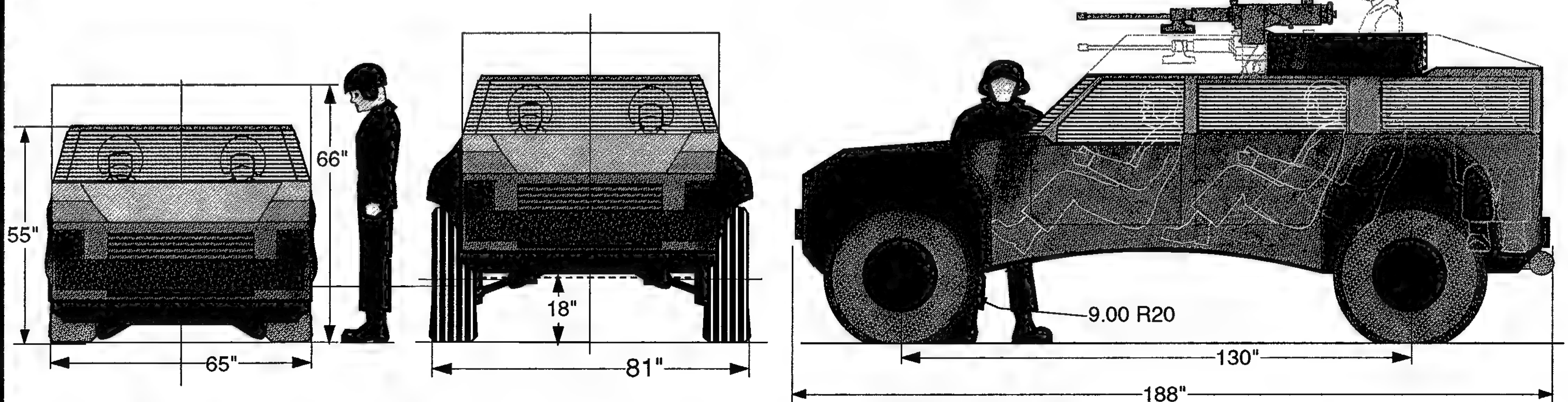
# RSTA-V 4 x 4 Baseline Concept

- MOBILITY > HMMWV
- LATERAL STABILITY ≥ HMMWV
- 1.5 TON PAYLOAD, 4 TON GVW
- FULL V22 COMPATIBILITY
- VARIABLE HEIGHT/WIDTH CONTROL
- PNEUMATIC, "FOLDING" SUSPENSION
- CENTRAL TIRE INFLATION
- DIESEL/ELECTRIC POWER
- BATTERY/CAPACITOR ENERGY STORAGE
- IN-HUB ELECTRIC TRACTION DRIVE
- FULL TRACTION/BRAKING CONTROL
- REMOTELY CONTROLLABLE
- INHERENT FUTURE GROWTH PROVISIONS





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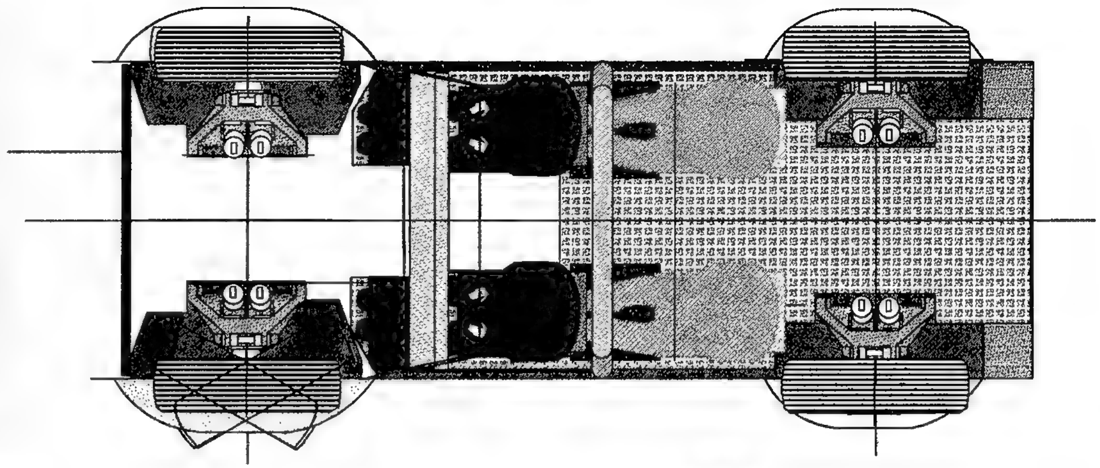
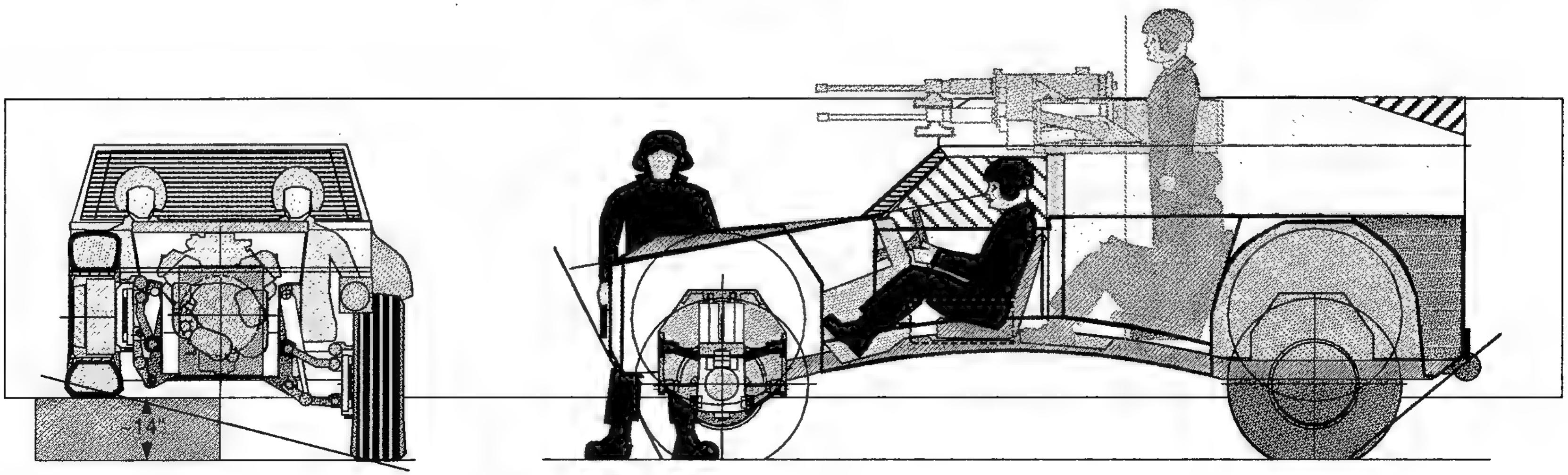
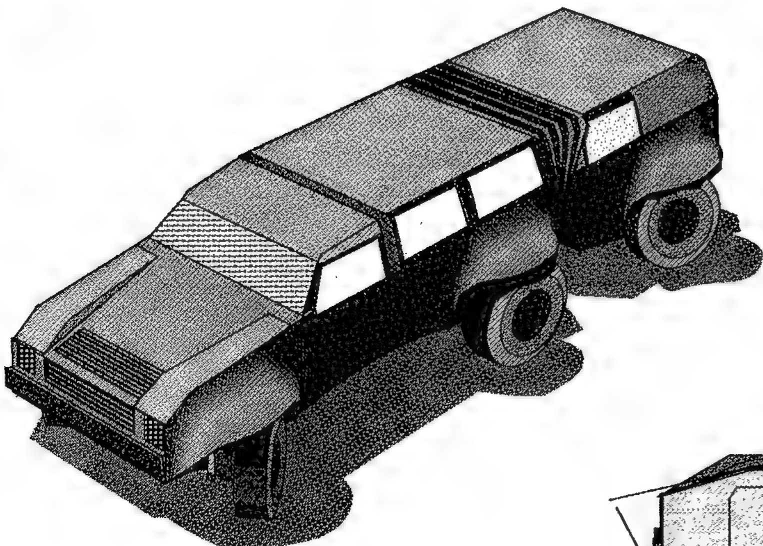
# RSTA-V 4 x 4 Concept

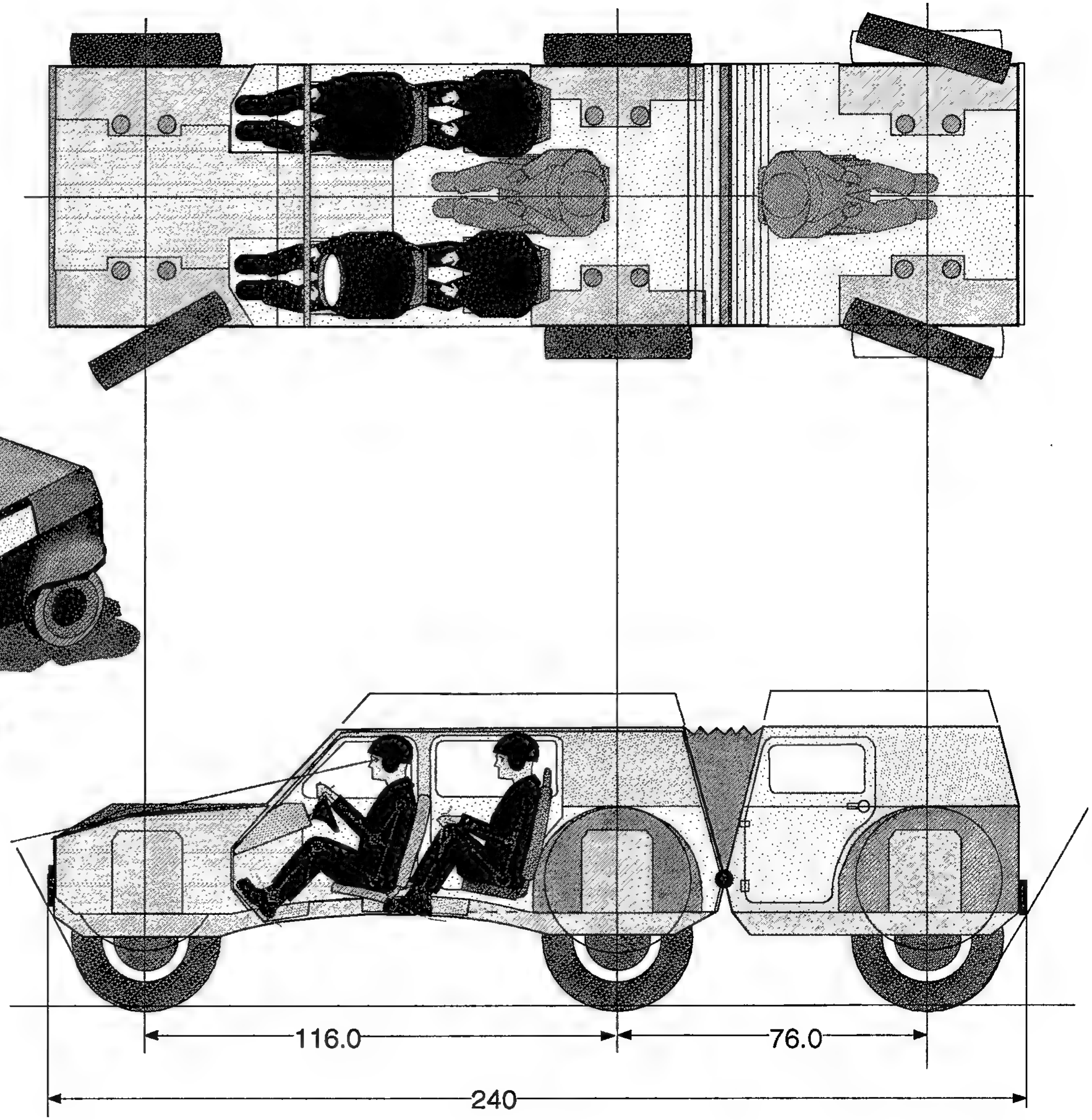
MOBILITY ~ HMMWV
LATERAL STABILITY~HMMWV
5 TON GVW
VARIABLE HEIGHT/WIDTH CONTROL
CENTRAL TIRE INFLATION
FULL V22 COMPATIBILITY
IN-HUB ELECTRIC TRACTION DRIVE
FULL TRACTION/BRAKING CONTROL
REMOTELY CONTROLLABLE
RIDE CONTROL



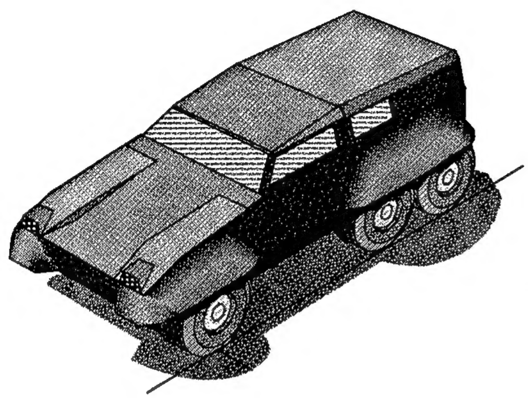


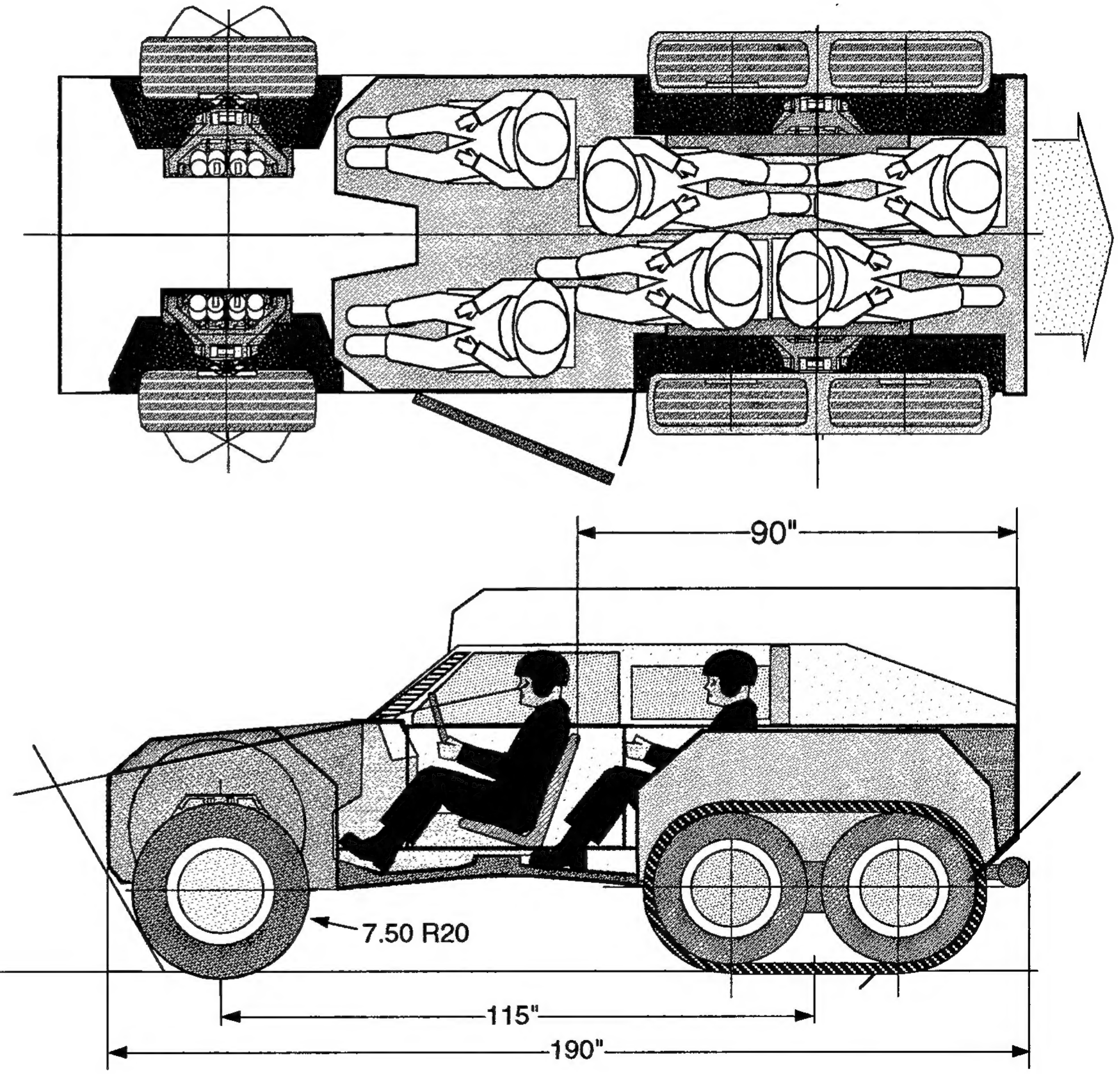
# LEADING 6X6 SEMI-ARTICULATED RSTV CONCEPT

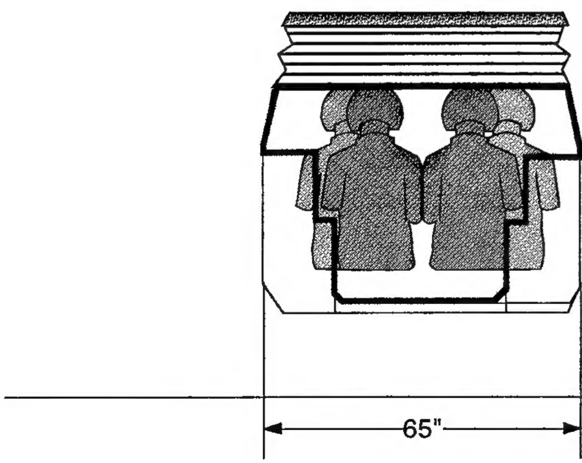




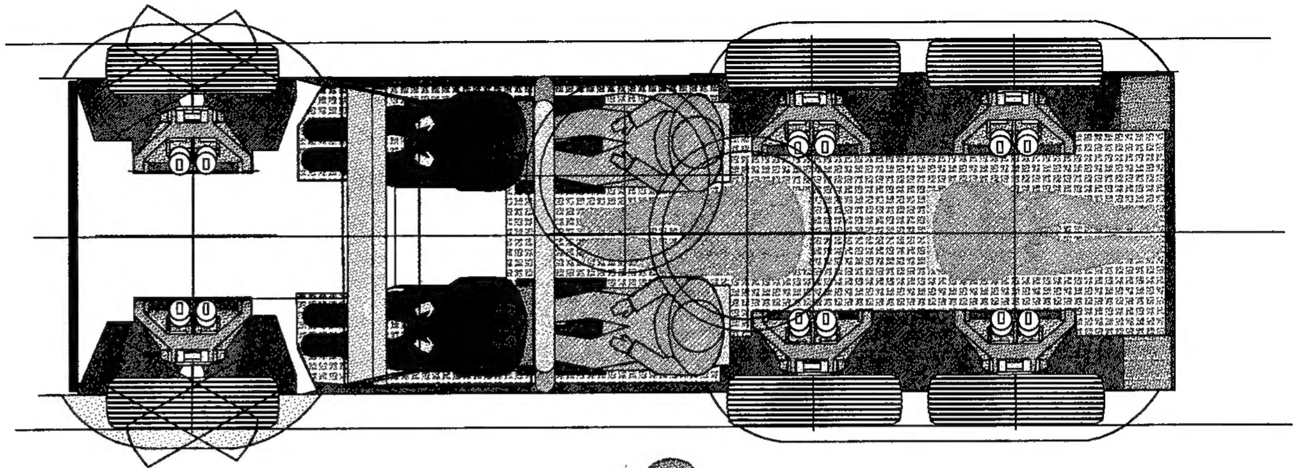
# RSTA-V 6 x 6 WHEEL/TRACK CONCEPT

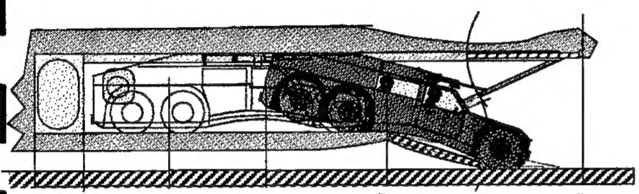


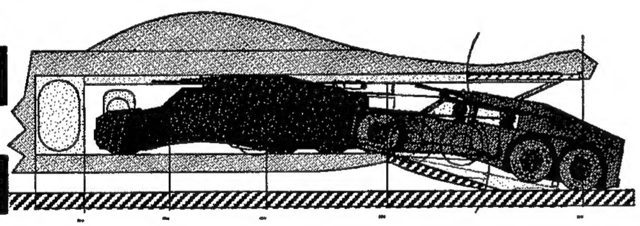


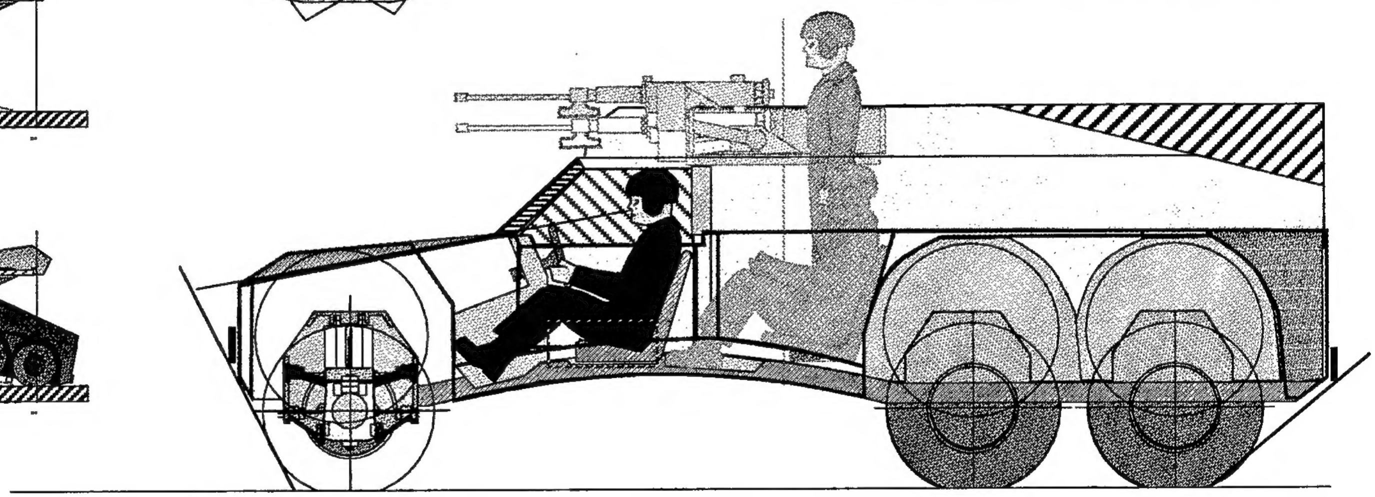



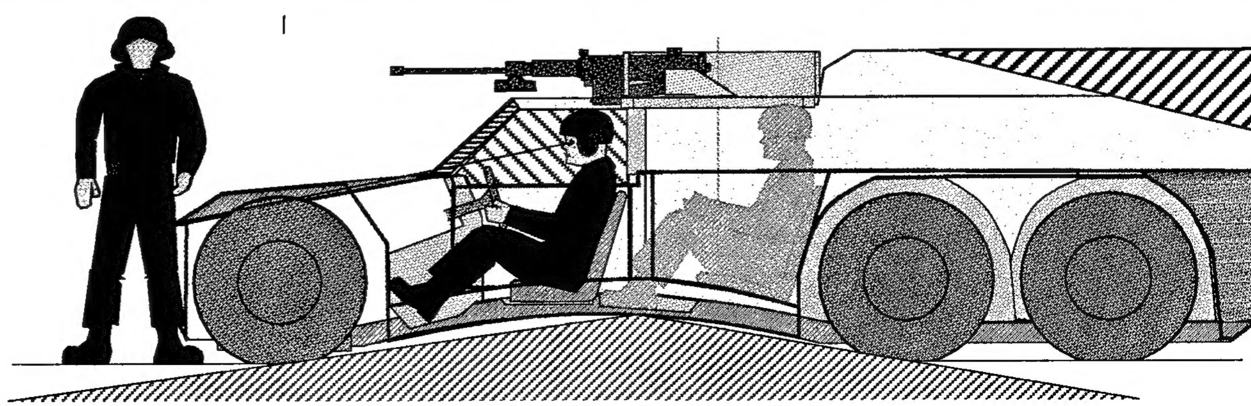
# STRETCHED 4-DOOR 6x6 CONCEPT



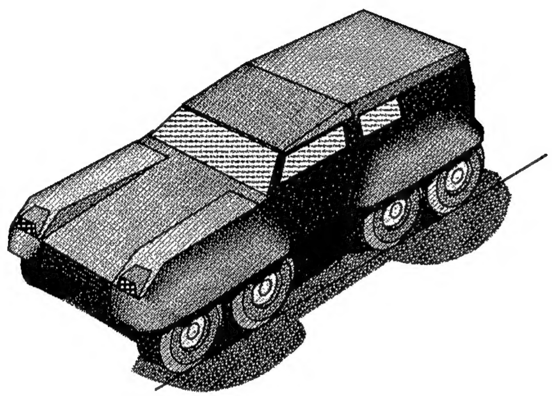


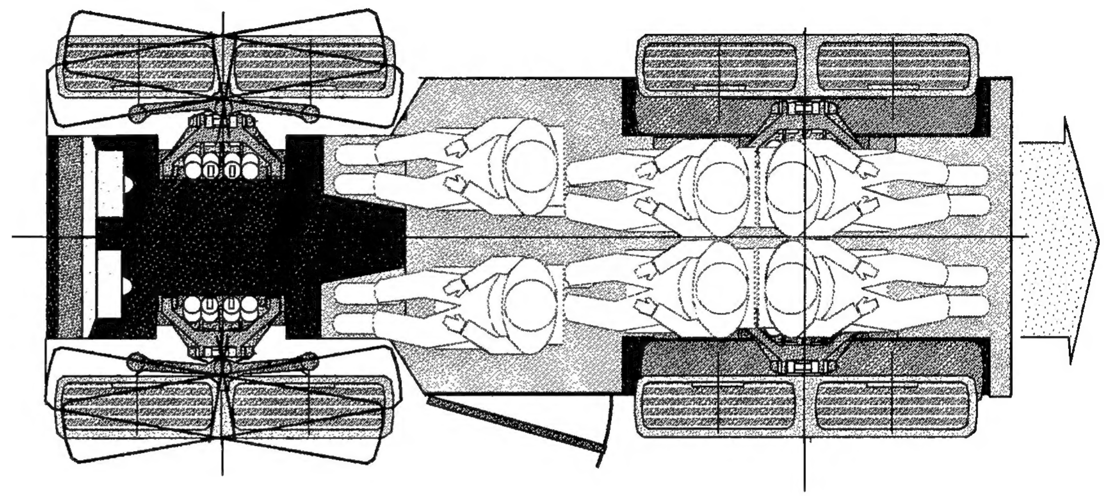


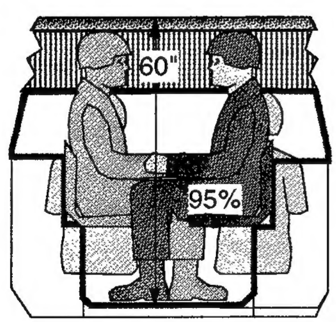


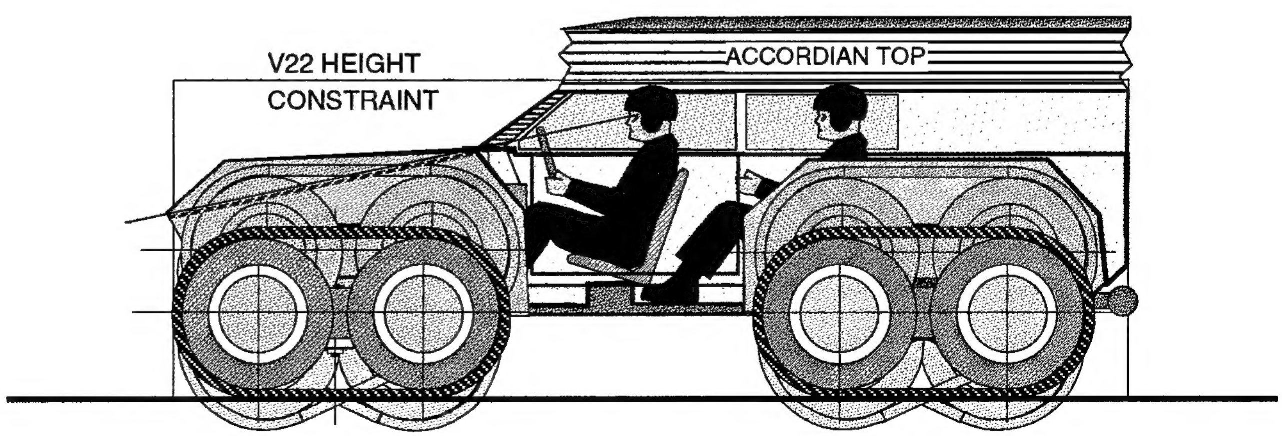


# RSTA-V 8 x 8 WHEEL/TRACK CONCEPT







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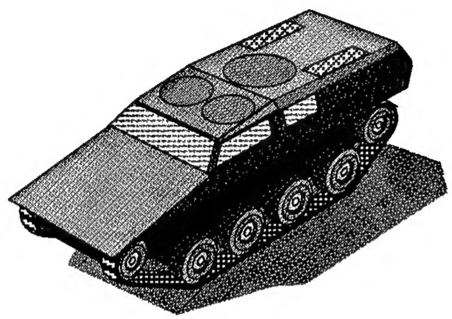
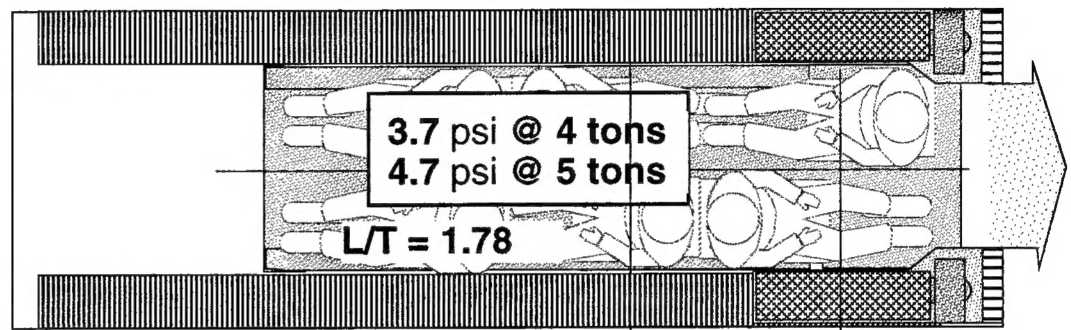
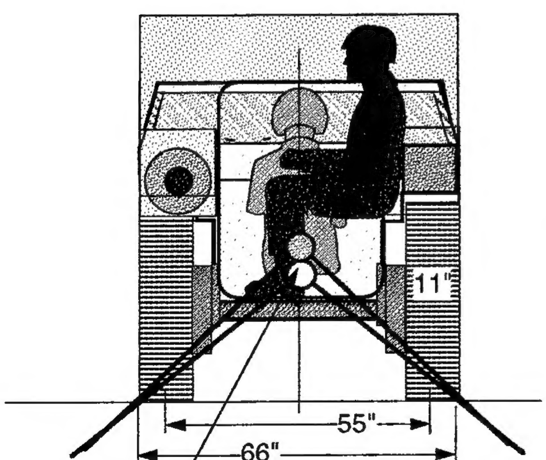
# RSTA-V TRACKED CONCEPT






Required CofG ht
for roll stability
equal to HMMWV